PUGET SOUND AND APPROACHES

A Literature Survey

VOLUME I

Geography

Climatology

Hydrology

University of Washington Department of Oceanography

Seattle 5, Washington

UNIVERSITY OF WASHINGTON DEPARTMENT OF OCEANOGRAPHY
SEATTLE 5, WASHINGTON

PUGET SOUND AND APPROACHES
A LITERATURE SURVEY

Volume I

Work Performed Under

Contract No. Nonr-447(00)

Task Order 477(06)

of the

Office of Naval Research

August, 1953

Richard H. Fleming
Executive Officer

ACKNOWLEDGMENT

The material for this report has been arranged and coordinated by Mr. Peter M. McLellan under the technical supervision of Dr. Clifford A. Barnes.

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FORWARD

The Literature Survey of Puget Sound and Approaches has been completed by the Department of Oceanography of the University of Washington as authorized by the Office of Naval Research Contract Nonr-447(00), Task Order 447(06). Under the terms of this contract the Department of Oceanography has provided a listing and analysis of all published and unpublished literature pertaining to the oceanography and factors influencing the oceanography of Puget Sound.

To effectively accomplish general oceanographic research in an area in which outside influences of every type play an important or undetermined role, every possible factor must be taken in consideration. For this reason all of the factors that may influence the oceanography of Puget Sound have been included. The form of the paper is essentially that of an abstract of the current knowledge on each subject. Appended to each subject is a detailed, annotated bibliography of all relevant publications and unpublished reports and data, whether used in the abstract or not. If no information is available on a certain subject this has been mentioned in order to present the status of our knowledge to date.

PUGET SOUND AND APPROACHES
A LITERATURE SURVEY

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SECTION 1: GEOGRAPHY

15 January 1953

GEOGRAPHY

PHYSICAL GEOGRAPHY

LOCATION

Puget Sound is located in the northwestern section of the state of Washington (Fig. 1-1). The name Puget Sound has been applied to various local geographic areas and features. In this report it will be found applied to a specific water area and its approaches. It also will appear prefixed to a drainage basin and a regional area.

The regional area, Puget-Willamette Trough, extends from the Klamath Mountains in southwestern Oregon to the Fraser River in British Columbia between the Coast and Cascade Mountain Ranges. The northern section of this long, narrow north-south aligned trough is commonly called the Puget Sound Lowlands. In this report the regional area will also be referred to as the Puget Sound Basin when it is desired to include the mountain drainage area with that of the lowland. The Puget Trough extends from the Fraser River on the north to the divide between the Chehalis and Cowlitz River Basins to the south, which separates the northern section of this trough from the Willamette Lowland. Within the center of the Puget Sound Basin is located the body of water extending south from (1) Middle Point, on the west, and Point Partridge, on the east, (2) Deception Pass, and (3) Swinomish Slough. The three entrances named above constitute the water boundaries of Puget Sound. The water approaches to Puget Sound may be assumed to be adjacent to these entrances (Fig. 1-2).

DESCRIPTION OF AREA

Puget Sound is characterized by numerous channels, sounds, and inlets. It occupies an area of 767 square nautical miles compared to the whole basin area of 11,000 square nautical miles. The entire system lies within an area of about 40 by 90 nautical miles (see section on Hydrography: Bathymetry). Through the Middle Point-Point Partridge entrance passes approximately 95 per cent of the volume of water entering or leaving Puget Sound. Approximately five per cent flows through Deception Pass, while the contribution of water from Swinomish Slough may be considered negligible. The Strait of Juan de Fuca interposes between Washington Sound to the north, and Puget Sound to the south, as well as between Vancouver Island and the Olympic Peninsula. That section of Puget Sound connecting with the strait, and lying between Point Wilson and Point No Point on the west, and Whidbey Island on the east, is known as Admiralty Inlet. Hood Canal, a long narrow arm of Puget Sound, extends southward about 50 nautical miles. As the result of its great length, narrowness, depth, and weak tidal currents, Hood Canal has many

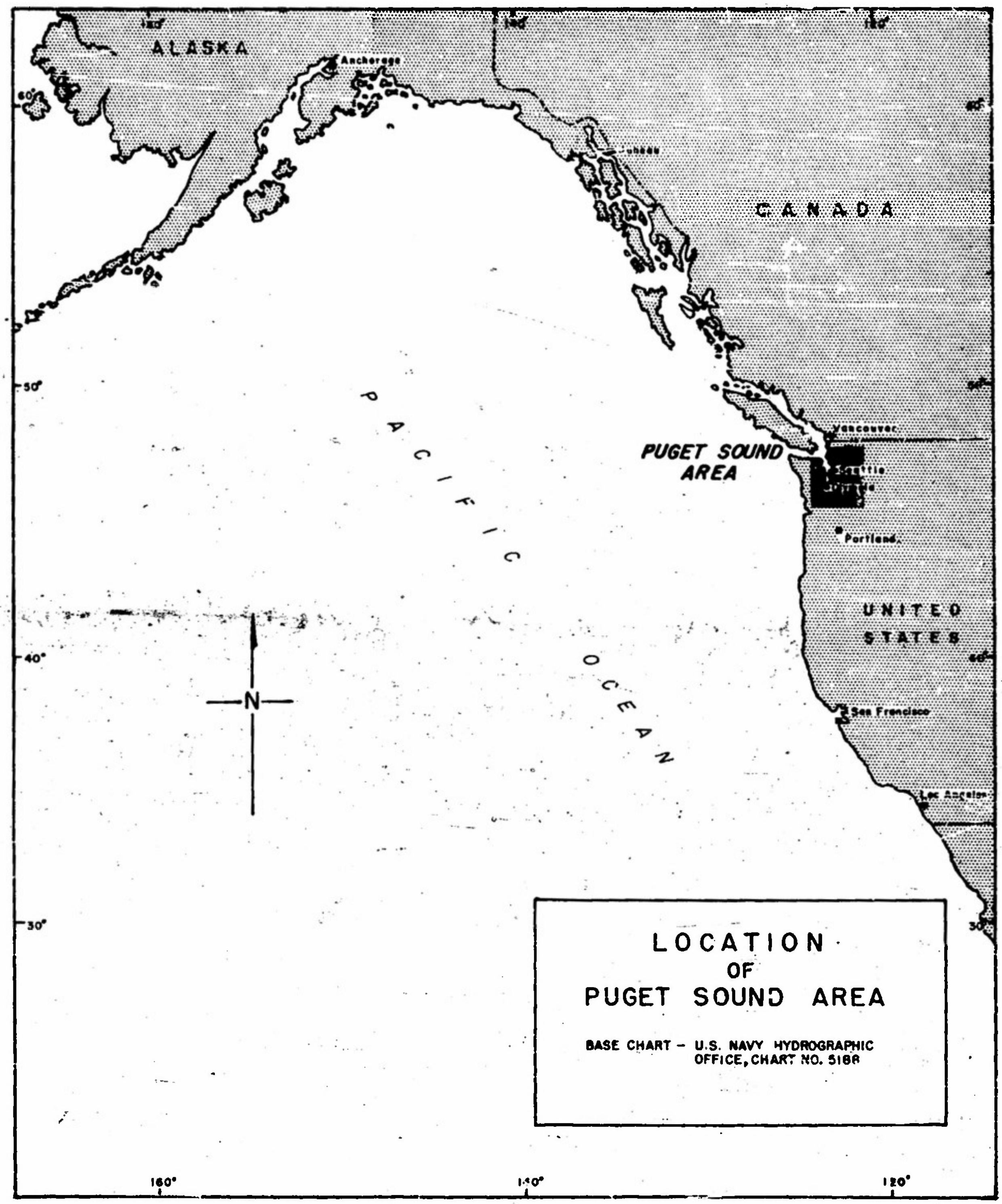

ALASKA
Anchorage
CANADA
PUGET SOUND AREA
Vancouver
Seattle
Portland
UNITED STATES
San Francisco
Los Angeles
PACIFIC OCEAN
N
50°
40°
30°
160°
140°
120°
LOCATION OF PUGET SOUND AREA
BASE CHART - U.S. NAVY HYDROGRAPHIC OFFICE, CHART NO. 5188

Fig. 1-1

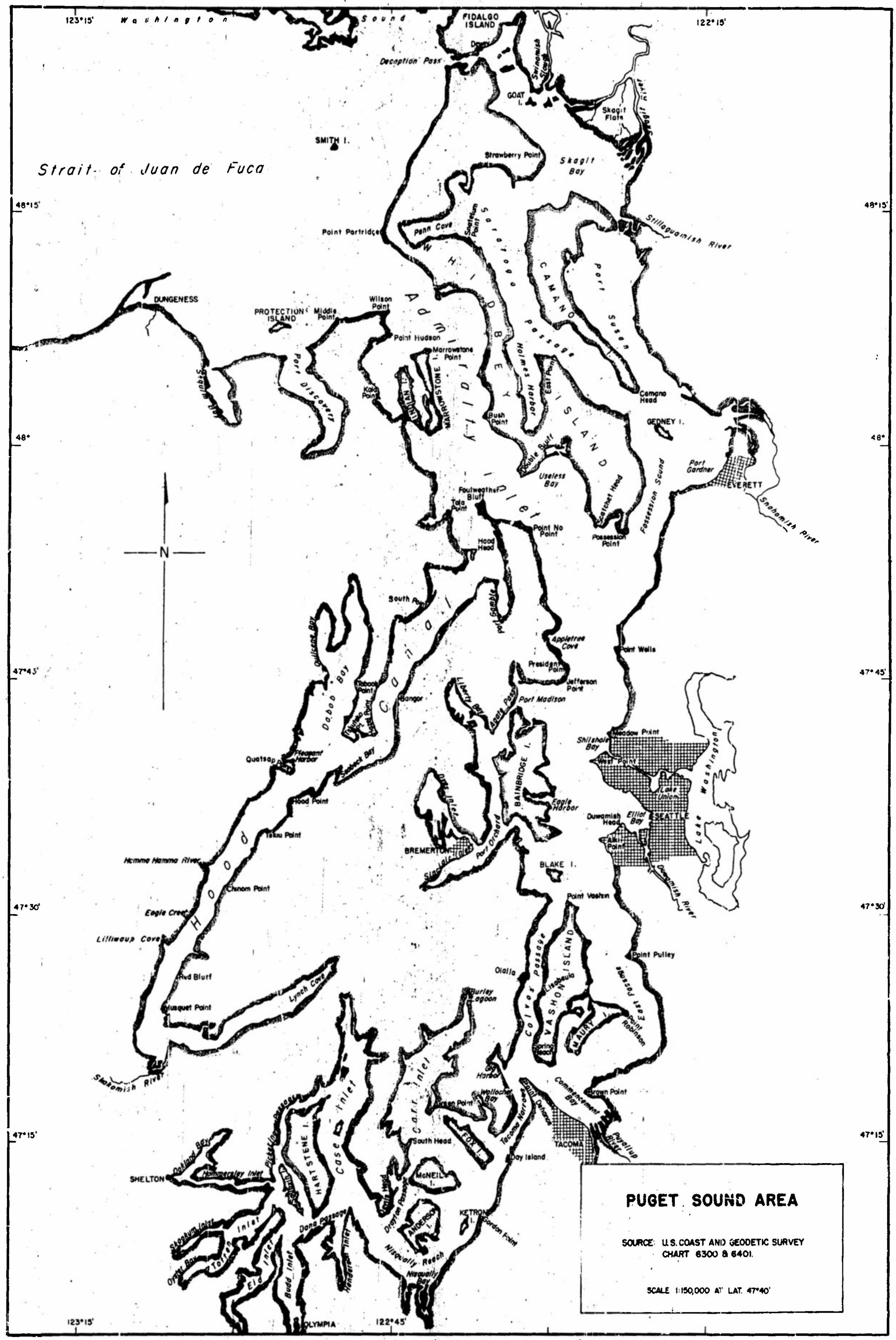

PUGET SOUND AREA
SOURCE: U.S. COAST AND GEODETIC SURVEY CHART 6300 & 6401.
SCALE 1:150,000 AT LAT. 47°40'
123°15'
122°15'
122°45'
48°15'
48°
47°45'
47°30'
47°15'
Strait of Juan de Fuca
Washington Sound
FIDALGO ISLAND
Deception Pass
SMITH I.
Skagit Bay
Skagit Flats
Stillaguamish River
Strawberry Point
Penn Cove
Point Partridge
DUNGENESS
PROTECTION ISLAND
Middle Point
Wilson Point
Point Hudson
Marrowstone Point
Port Discovery
Admiralty Inlet
WHIDBEY ISLAND
CAMANO
Saratoga Passage
Port Susan
Holmes Harbor
Camano Head
GEDNEY I.
Port Gardner
EVERETT
Snohomish River
Possession Sound
Useless Bay
Double Bluff
Foulweather Bluff
Point No Point
Possession Point
Hood Head
South Pt.
Appletree Cove
Point Wells
President Point
Jefferson Point
Port Madison
Dabob Bay
Bangor
Meadow Point
Shilshole Bay
West Point
Lake Union
Lake Washington
SEATTLE
Duwamish Head
Elliot Bay
Alki Point
Duwamish River
BAINBRIDGE I.
Eagle Harbor
BREMERTON
Port Orchard
BLAKE I.
Quatsap
Pleasant Harbor
Seabeck Bay
Hood Point
Hamma Hamma River
Eagle Creek
Lilliwaup Cove
Hood Canal
Red Bluff
Musquet Point
Lynch Cove
Skokomish River
Point Vashon
Point Pulley
Olalla
Burley Lagoon
Colvos Passage
VASHON ISLAND
MAURY
Point Robinson
East Passage
Commencement Bay
Brown Point
TACOMA
Puyallup River
Tacoma Narrows
Day Island
FOX I.
Carr Inlet
Case Inlet
HARTSTENE I.
SHELTON
Oakland Bay
Hammersley Inlet
McNEIL I.
ANDERSON
KETRON I.
Nisqually Reach
Nisqually
Dana Passage
Totten Inlet
Eld Inlet
Budd Inlet
Henderson Inlet
OLYMPIA
Oyster Bay
Skookum Inlet
South Head

Fig. 1-2.

characteristics which distinguish it from the remaining waters of the region, as will be brought out later in the section on Physical Oceanography.

Puget Sound proper is connected with the Strait of Juan de Fuca by a series of waterways to the east of Whidbey Island: Possession Sound, Saratoga Passage, Skagit Bay, and Deception Pass. The width of these deep waterways decreases with progress northward but shoals and tidewater flats frequently give a total width of as much as five nautical miles. Deception Pass separates Whidbey Island from Fidalgo Island and connects the Strait of Juan de Fuca with Skagit Bay. Although two miles in length it is extremely narrow and shallow, in some places only 200 yards across with a depth of 96 feet. The Swinomish Slough, near Deception Pass, connects Skagit Bay with Padilla Bay to the north. The slough has a dredged depth of 12 feet and a minimum width of 100 feet (U. S. Department of Commerce Coast and Geodetic Survey 1951). See work performed by U. S. Engineers, this section.

All these waters are connected with their approaches to the Strait of Juan de Fuca which in turn opens westward to the Pacific Ocean. Refer to section on Hydrography for detailed bathymetry.

Shore Line Features

The shore line of Puget Sound and the Pacific Coast is very dissimilar in character compared with that of the Atlantic Coast. The Atlantic Coast line is largely composed of mud and sand formations with comparatively little elevation, whereas the Pacific Coast of Washington is predominantly rocky and precipitous. The Atlantic and Gulf Coasts have many excellent harbors scattered from Maine to Texas where vessels may seek refuge in time of storm. Quite opposite conditions exist on the Pacific Coast where there are few harbors and these widely scattered. After leaving Puget Sound and the Strait of Juan de Fuca (the northern boundary of Washington), the next point of refuge to the south is Grays Harbor, a distance of nearly 100 miles, and after that Willapa Bay and the Columbia River; the last named separating Washington and Oregon. Puget Sound is the only harbor along the Northwest Coast of the United States which may be made under all weather conditions.

The total shore line length of Puget Sound enclosed by the northern boundary to Admiralty Inlet (Middle Point-Point Partridge), Deception Pass, and the Swinomish Slough is 1,157 nautical miles (1,332 statute miles). Of this distance, the greater proportion is faced by bluffs ranging from 50 to 500 feet in height that are composed of glacial till and material deposited during the past ice age. A generally narrow beach line is experienced at the base of these bluffs with depths of water exceeding 50 to 100 feet close to the shore along these portions of the Sound. Near river deltas, tidal flats extend for several miles in some cases as, for example, near the mouth of the Skagit River. At the extreme southern end of Puget Sound, prairie lowlands face the water as a continuation of the Puget Lowland.

Throughout the region dense coniferous forests are encountered. Except where man has cut away the forests to build farms, resorts, and towns, the Douglas Fir, cedar, and hemlock trees grow out to the beach line or overhang the high bluffs so that it is difficult to identify the several points from their similarity in appearance. For oblique aerial photographs of harbors and important points in Puget Sound, refer to the Marine Atlas of the Northwest (Morris and Heath 1952). In addition to this recent publication the Corps of Engineers, U. S. Army has published aerial photographs in their Port Series publications (U. S. Army Corps of Engineers and U. S. Maritime Commission 1938a, 1938b; U. S. Army Corps of Engineers and U. S. Shipping Board 1932a, 1932b, 1932c).

Tracks of the Great Northern Railway parallel the east shore of Puget Sound from Tacoma to Bellingham. Between Seattle and Everett the tracks lie just above the beach line or form bulkheads where no beach exists. See section on Physical Oceanography: Water Movements, for the effect of waves and surf on these installations.

Beaches

Puget Sound, while faced by high bluffs, has a considerable number of beaches. Cursory analysis has been made locating the beaches in the central section, from Point No Point, on the north, to the Tacoma Narrows, on the south. The beaches have been described with respect to A. Type, Composition, and Trafficability, and B. Access. In general, Puget Sound beaches consist of either a gray coarse sand or a mixture of such sand with small gravel, which deposits are seldom wide enough to be indicated on a map of the scale used in this survey (see Geology section for analysis of sediments). The beaches usually form only a narrow strip along the shore. See photographs contained in the Marine Atlas of the Northwest (Morris and Heath 1952) and refer to Fig. 1-6 for beach locations and Appendix 1-A for their descriptions.

No accurate information is available as to beach slope but few if any are more than 5 per cent (King County Planning Commission 1952). An intensive beach survey could well be carried out throughout the Puget Sound area (see section on Hydrography: Field Surveys).

POTENTIAL LANDSLIDE AREA

Landslides occur with such frequency along the shore of Puget Sound that the lives of a considerable percentage of the population are affected, not only through the damage or destruction of private and public property, but far more specifically by introducing the indeterminate factor of danger, which lessens personal sense of security, injures property values, and makes difficult the financing of new construction. With the high percentage of shore line composed of bluffs 50 to 500 feet high just in back of the beach line the problem of landslides may be fully appreciated. Since the principal process of erosion between sea and shore is that of landslide and slumping, slides may be expected to continue unless definite local measures are taken to protect specific local property sites.

It has been pointed out (Hennes 1936) that uplift is the most common cause of slides in the Seattle region (see Geology section).

THE SURROUNDING MOUNTAINS

The Cascade range lying to the east of Puget Sound is the most prominent relief feature in Washington. It divides the state both climatically and physiographically along a north-south axis. The Olympic Mountains on the west separate Puget Sound from the direct influence of the Pacific Ocean. These mountains are a part of a discontinuous coast range extending from California to Canada. They are separated on the north from the mountains of Vancouver Island by the Strait of Juan de Fuca and on the south from the Willapa Hills by the Chehalis Valley Gap. The general elevation of these mountains increases from south to north where peaks rise to heights approaching that of Mount Olympus, 7,954 feet (Fig. 1-3).

Fig. 1-3 PUGET SOUND DRAINAGE BASIN

CULTURAL GEOGRAPHY

EXPLORATION AND EARLY HISTORY

An outline of the periods of exploration and early history of the Puget Sound area is presented as Table 1-1 to orient the reader with the relative recency and sequence in which events have taken place. A territorial census in 1853 showed the region to have 2,063 inhabitants, about half of whom were located in the area of southern Puget Sound. Table 1-2 shows population growth in the Puget Sound area. The population of the basin in 1950 was 1,400,000.

THE NAME "PUGET SOUND"

At the present time a certain amount of confusion is present with respect to the exact location of the area designated by PUGET SOUND. A brief history of the evolution of the term may suffice to explain the reason for this misunderstanding. From the original Journal, Book II, Chapter VI of Captain George Vancouver, discoverer of PUGET SOUND in May 1792, the following account is given.

> Thus by our joint efforts, we had completely explored every turning of this extensive inlet; and to commemorate Mr. Puget's exertions, the south extremity of it I named Puget's Sound.

(Meany 1907)

In Charles Wilkes, United States Exploring Expedition during the years 1838-1842, chapter on Hydrography, no. 16, page 320, PUGET SOUND is defined as follows:

> Puget's Sound embraces the extent of waters lying within the Narrows [Tacoma Narrows], which is the only channel by which it can be reached.

(Wilkes 1858)

The Coast and Geodetic Survey's United States Coast Pilot, Pacific Coast, California, Oregon and Washington, 1951 edition, Page 457, reads as follows:

> Puget Sound (chart 6401) extends about 53 miles in a general southerly direction from Point Wilson and then turns southwestward for about 30 miles, expanding into numerous inlets

TABLE 1-1. The Early History of the Puget Sound Area

	Early explorations of the northwest coast of the United States were conducted by the Spanish, English, Russians, and Americans.
1792	The culmination of northwest discovery by sea was made by Captain George Vancouver when the southernmost portion of this inland sea was discovered and named Puget Sound.
1832	The first permanent settlement by Europeans on the shore of Puget Sound was established by the Hudson Bay Company at Fort Nisqually on Nisqually Bay.
1838-1842	The United States Exploring Expedition commanded by Lt. Charles Wilkes contributed many important phases to the history of Puget Sound.
1839	The Puget Sound Agricultural Company was formed from the Hudson Bay Company to increase British population in the area.
1846	Treaty was established between Great Britain and the United States dividing Old Oregon along the 49th parallel between the two countries. Mission on Budd Inlet established--the future Olympia.
1850	Whidbey Island, Steilacoom, and Port Townsend were settled.
1851	Seattle settled. Gold rush in California inaugurated heavy shipping of wharf piles and structural timbers for San Francisco.
1852	Coal discovered in Bellingham.
1853	Washington territory established.
1873	Final international boundary settlement made by a Berlin Arbitration Committee in which charts drawn by the early explorers were used to determine rights to the San Juan Islands.
1889	The State of Washington established.

Table styled after that of Meany (Meany 1924).

TABLE 1-2. Population in the Puget Sound Region by Counties and Major Cities 1860-1950.

COUNTY	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950
Clallam	149	408	638	2,771	5,603	6,755	11,368	20,449	21,848	26,396
Island	294	626	1,087	1,787	1,870	4,704	5,489	5,369	6,098	11,079
Jefferson	531	1,268	1,712	8,368	5,712	8,337	6,557	8,346	8,918	11,618
King	302	2,120	6,910	63,989	110,053	284,638	389,273	463,517	504,980	732,992
Kitsap	544	866	1,738	4,624	6,767	17,647	33,162	30,776	44,387	75,724
Mason	162	289	639	2,826	3,810	5,156	4,919	10,060	11,603	15,022
Pierce	1,115	1,409	3,319	50,940	55,515	120,812	144,127	163,842	182,081	275,876
San Juan	(1)	554	948	2,072	2,928	3,603	3,605	3,097	3,157	3,245
Skagit	(1)	(1)	(1)	8,747	14,272	29,241	33,373	35,142	37,650	44,273
Snohomish	(2)	599	1,387	8,514	23,950	59,209	67,690	78,861	88,754	111,580
Thurston	1,507	2,246	3,270	9,675	9,927	17,581	22,366	31,351	37,285	44,884
Whatcom	352	534	3,137	18,591	24,116	49,511	50,600	59,128	60,355	66,733
Total	4,956	10,919	24,785	182,904	264,523	607,194	772,529	909,938	1,007,116	1,418,422
MAJOR CITIES										
Bellingham	-	-	-	8,135	11,06[illegible]	24,298	25,585	30,823	29,314	33,934
Bremerton	-	-	-	-	-	2,993	8,918	10,170	15,134	27,746
Everett	-	-	-	-	7,838	24,814	27,644	30,567	30,224	33,807
Olympia	-	1,203	1,232	4,698	3,863	6,996	7,795	11,733	13,254	15,711
Seattle	-	1,107	3,533	42,837	80,671	237,194	315,312	365,583	368,302	462,440
Tacoma	-	-	1,098	36,006	37,714	83,743	96,965	106,817	109,408	142,975
Total	-	2,310	5,863	91,676	141,148	380,038	482,219	555,693	565,636	716,613

(1) Included in Whatcom County
(2) Included in Island County

Styled after Washington State Statistical Abstract (Robinson 1952).

> and passages, the majority of which are navigable by deep-draft vessels. Admiralty Inlet is the northern portion of the Sound from Point Wilson to Foulweather Bluff.

(U. S. Department of Commerce Coast and Geodetic Survey 1951)

From a footnote on Page 148 of Vancouver's Discovery of Puget Sound, by Edmond S. Meany, the following description of what has happened to the name PUGET SOUND is presented as follows:

> These settlements [around Fort Nisqually] (except Fort Langley) were near the southern extremity of this inland sea--the very portion which Vancouver named Puget's Sound. That name became the familiar one, and as the white settlements moved northward along the shores that name was carried along regardless of other names, like Admiralty Inlet, Port Gardner, the Gulf of Georgia, and the Strait of Juan de Fuca. Puget Sound became the generic name for the whole region and is largely so used at the present time.*

(Meany 1907)

*Permission to quote granted by Binfords and Mort, publisher, 8/16/52.

INDUSTRIES BORDERING PUGET SOUND

The many inlets and bays adjoining the region from the vicinity of the Canadian Boundary south to Olympia, Washington, made Puget Sound a focal point for regional, national, and world trade. This area of protected inland waters, together with forests, minerals and mountain-fed streams, supports many manufacturing activities. A large portion of the population is dependent upon the Basin's manufacturing enterprises, which include lumber mills, pulp and paper mills, airplane, and shipyard industries, smelting, and fish and food processing plants. The 2,151 manufacturing establishments operating in 1947 produced commodities with a value of over one-half billion dollars (Federal Security Agency 1951a). For fishing see Marine Biology section.

With the increase of population and industry, pollution of the air and water is increasing (see section on Climatology: Atmospheric Pollution).

WATER POLLUTION

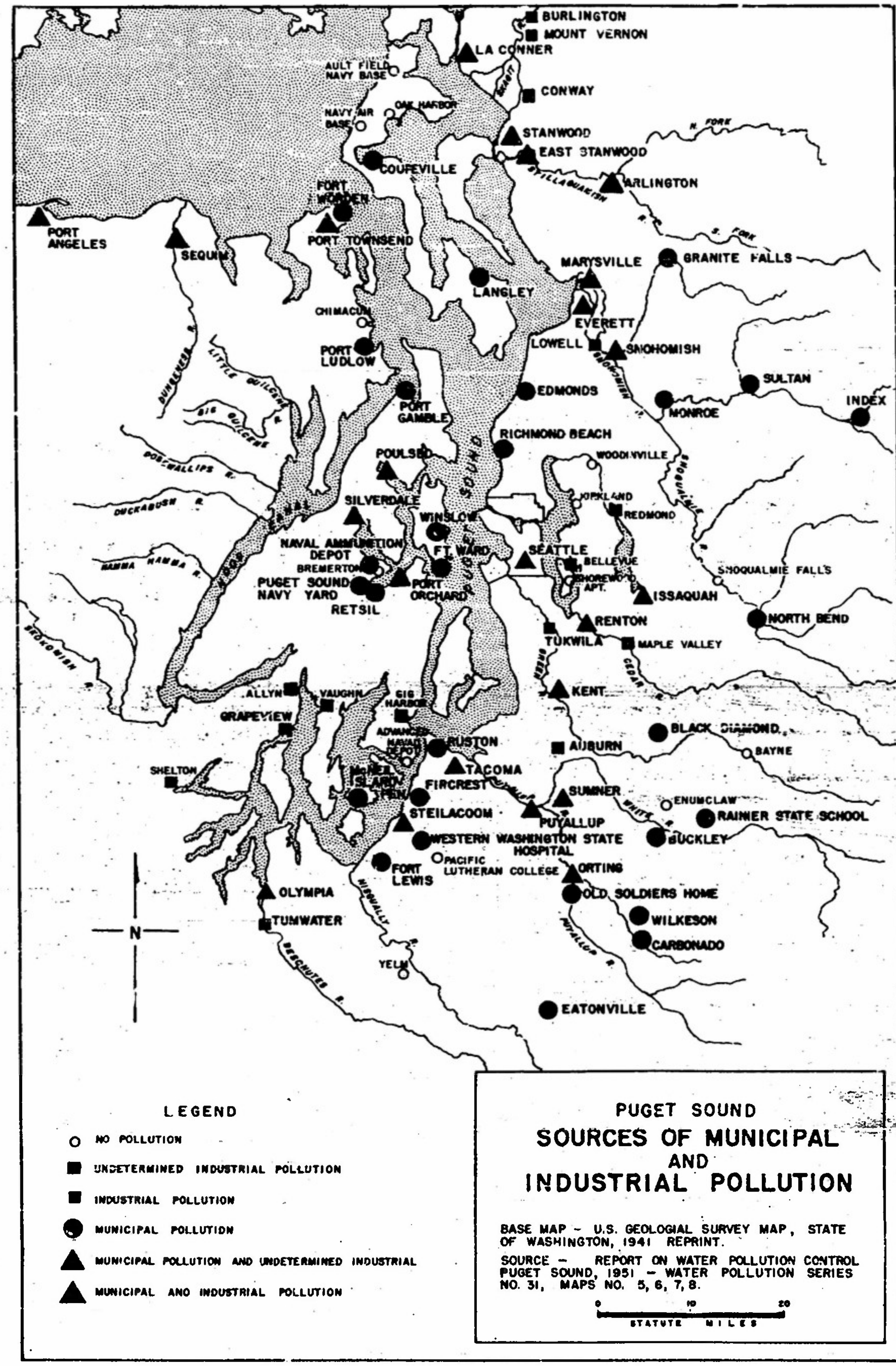
In spite of the large tidal prism (1.27 cubic nautical miles) in Puget Sound, the tides of long inland estuaries have peculiarities that are quite different from the tides in the open ocean (see section on Physical Oceanography). For this reason water pollution in Puget Sound, generally confined to certain areas of specific and concentrated industries has become a critical local factor. The Washington State Pollution Control Commission has deemed pollution to exist when the concentration of dissolved oxygen is reduced below 5 parts per million. Water pollution in the Puget Sound area results from domestic and industrial wastes and a variety of other substances discharged or otherwise allowed to enter the water. The major sources of pollution are the wastes discharged by 101 municipalities and 275 industries with separate outlets, sewage from unsewered suburban areas adjacent to the larger cities, and the silt, logs, bark, slashings, oil, garbage, and refuse which enter the water through erosion or carelessness in logging and other operations. The known organic waste discharges have a population equivalent of 6,500,000 persons. This is exclusive of wastes discharged by 7 municipalities and 116 industries which discharge inorganic wastes (Federal Security Agency 1951a).

Pollution exerts damaging effects on waters in the bays and estuaries and lower stretches of tributaries adjacent to the larger metropolitan and industrial areas on Puget Sound. In these waters it is particularly damaging to the fishery resources, property values, swimming and other recreation. See Fig. 1-4 for Sources of Municipal and Industrial Pollution. Refer to section on Marine Biology: Fish and Shellfish Kills for additional discussion.

The shipping industry itself is at times a source of pollution. The Seattle District, Corps of Engineers, reports that there are no regulations in effect at this time forbidding the pumping of ship bilges into the waters of Puget Sound, as such. The Oil Pollution Act of 1924 (33 U. S. Code 434-7) makes it unlawful to discharge oil into tidal navigable waters of the United States, and, of course, this would apply to bilge water if it contained oil. During World War II the discharge of oil-bearing ballast water was permitted at the discretion of the Captain of the Port. See the Federal Register, issue of 31 July 1943, Title 33, Part 207, Navigation Regulations (U. S. Army Corps of Engineers 1952a).

DUMPING GROUNDS

No dumping areas have been established in the waters of Puget Sound for waste matter or dredged material. In each case the person desiring to do so must make application to the Corps of Engineers, U. S. Army, and secure a permit in accordance with Section 13 of the River and Harbor Act of 1899. Except when the material is deposited in shallow water as fills, it is the Corps of Engineers' policy not to permit dumping in less than 50 feet of water at mean lower low water (U. S. Army Corps of Engineers 1952a).



BURLINGTON
MOUNT VERNON
LA CONNER
AULT FIELD NAVY BASE
CONWAY
NAVY AIR BASE
OAK HARBOR
STANWOOD
EAST STANWOOD
COUPEVILLE
ARLINGTON
FORT WORDEN
PORT TOWNSEND
PORT ANGELES
SEQUIM
MARYSVILLE
GRANITE FALLS
LANGLEY
CHIMACUM
EVERETT
LOWELL
SNOHOMISH
PORT LUDLOW
SULTAN
EDMONDS
INDEX
PORT GAMBLE
MONROE
RICHMOND BEACH
POULSBO
WOODINVILLE
SILVERDALE
KIRKLAND
REDMOND
WINSLOW
NAVAL AMMUNITION DEPOT
FT. WARD
SEATTLE
BREMERTON
BELLEVUE
SHOQUALMIE FALLS
PUGET SOUND NAVY YARD
PORT ORCHARD
ISSAQUAH
RETSIL
RENTON
NORTH BEND
TUKWILA
MAPLE VALLEY
KENT
ALLYN
VAUGHN
GIG HARBOR
GRAPEVIEW
BLACK DIAMOND
AUBURN
BAYNE
RUSTON
TACOMA
SHELTON
FIRCREST
SUMNER
ENUMCLAW
STEILACOOM
PUYALLUP
RAINIER STATE SCHOOL
BUCKLEY
WESTERN WASHINGTON STATE HOSPITAL
FORT LEWIS
PACIFIC LUTHERAN COLLEGE
ORTING
OLYMPIA
OLD SOLDIERS HOME
TUMWATER
WILKESON
CARBONADO
YELM
EATONVILLE
N
LEGEND
NO POLLUTION
UNDETERMINED INDUSTRIAL POLLUTION
INDUSTRIAL POLLUTION
MUNICIPAL POLLUTION
MUNICIPAL POLLUTION AND UNDETERMINED INDUSTRIAL
MUNICIPAL AND INDUSTRIAL POLLUTION
PUGET SOUND
SOURCES OF MUNICIPAL AND INDUSTRIAL POLLUTION
BASE MAP - U.S. GEOLOGICAL SURVEY MAP, STATE OF WASHINGTON, 1941 REPRINT.
SOURCE - REPORT ON WATER POLLUTION CONTROL PUGET SOUND, 1951 - WATER POLLUTION SERIES NO. 31, MAPS NO. 5, 6, 7, 8.
0 10 20
STATUTE MILES

Fig. 1-4

From the records of the Seattle City Engineer the only extensive dumping in the waters surrounding Seattle was from Denny Hill regrade in 1931, in which over four million cubic yards of material were dumped in Elliott Bay (City of Seattle Department of Engineering 1952). As reported by the City of Seattle Department of Engineering, the permit from the U. S. Engineers Office reads as follows:

> The area into which the material from Denny Hill No. 2 may be deposited is bounded as follows:
>
> On the north by the prolongation of the south side of Denny Way; on the south by the prolongation of the north side of Pier 14; on the east by a line tangent to the base of Magnolia Bluff from the northeast corner of Pier 8; and on the west described and 2000 feet therefrom.

(City of Seattle Department of Engineering 1952)

Ballast Dumps

A potential source of confusion in undertaking a detailed analysis of the bottom sediments of Puget Sound may be the occurrence of exotic rock types. Vessels which came from ports all over the world to carry Washington coal and lumber dumped their rock ballast into the water upon arrival in Puget Sound. Generally this happened near the piers but may be expected at any location. Only one pier was available in the earlier days in the Port of Seattle. Here, near Washington Street and Railroad Avenue South, from 30 to 40 thousand tons of San Francisco's Telegraph Hill lies buried. Ballast Island was built with rocks from Liverpool, Hongkong, Valparaiso, Honolulu, Melbourne, Mazatlan, and way points. Since then this material has been incorporated with other fill material to form the larger Harbor Island (McDonald 1942).

At Port Madison an old ballast dump is nearly bare at low water, lying about 75 yards offshore and about 400 yards in from the eastern entrance point (U. S. Department of Commerce Coast and Geodetic Survey 1951).

RIVER AND HARBOR MODIFICATION PROJECTS

Earliest fills were made with sawdust from the pioneer Yesler's sawmill and rock ballast thrown overboard from vessels.

During the period from 1895 to 1931 the City of Seattle engaged in regrading the hills of the business district and along the waterfront. More than 60 regrade projects were completed in which over 50 million cubic yards of earth were dumped into Elliott Bay or used to fill mud flats and low places in the city.

In a seventy-year span Seattle Harbor has changed; a new waterfront was made, hills were regraded, river beds were straightened out and made navigable, and lakes were joined (McDonald 1942, McElhoe, Jr. 1950).

The improvement of the rivers and harbors of the United States and miscellaneous other civil works are under the charge of the Corps of Engineers, U. S. Army. The following major navigation improvements are, or have been, undertaken by the Corps of Engineers, Seattle District, and are in or effect Puget Sound within the boundaries set forth at the beginning of this report:

Active	Inactive
Everett Harbor	Hammersley Inlet
Lake Crockett	Port Orchard Bay
Lake Washington Ship Canal	Skagit River
Olympia Harbor	Stillaguamish River
Port Gamble Harbor	Waterway connecting Port Townsend Bay with Oak Bay
Puget Sound and its tributary waters	
Seattle Harbor	
Swinomish Slough	
Tacoma Harbor	

For a complete description of these projects the reader is referred to the Annual Report of the Chief of Engineers (U. S. Army Corps of Engineers Annual).

River Deltas and Flood Control Projects

The principal cities along Puget Sound are all situated at the mouths of major rivers. There is, therefore, a constant stress of maintaining navigable channels within each major river mouth, all of which contain wharfs and piers. The towns and river names are as follows: Olympia (Deschutes River), Tacoma (Puyallup River), Seattle (Duwamish River), Everett (Snohomish River), and at the head of Skagit Bay--the Skagit River leads to Mount Vernon. The Corps of Engineers are charged with the maintenance of these facilities. The periodic formation and self-destruction of the Puyallup River Delta in the Tacoma harbor are discussed in the Geology Section.

The Corps of Engineers are also authorized to participate in the improvement of the navigable waters or their tributaries for flood control purposes, if such projects are economically justified and if the lives and social security of people are otherwise adversely affected.

Following is a tabulation of major flood control projects which are, or have been, undertaken by the Corps of Engineers, Seattle District, Washington, and affect the waters of Puget Sound within the boundaries set forth at the beginning of this report:

Active	Inactive
Mud Mountain Dam, White River	Eagle Gorge Reservoir, Green River
Stillaguamish River	Skagit River
Tacoma, Puyallup River	Upper Puyallup River

Complete project descriptions may be found in the Annual Report of the Chief of Engineers (U. S. Army Corps of Engineers Annual).

Canals and Locks

At the present time there are two canals within Puget Sound (Fig. 1-5). The Lake Washington Ship Canal had in 1949 as a limiting depth 27 1/2 feet (U. S. Department of Coast and Geodetic Survey 1951). The Canal was constructed in the period 1901 to 1916 and was opened for use in 1917. The Canal extends from Puget Sound through Shilshole Bay, Salmon Bay, Lake Union, Portage Bay, and Union Bay to deep water in Lake Washington. Included in this system are two parallel ship locks having a lift of 26 feet, one being for large vessels, and one for the small boats. The presence of this canal has added about 100 miles to the waterfront of Seattle.

The Port Townsend Canal connects Port Townsend with Oak Bay and had a limiting depth in 1949 of 15 feet (U. S. Department of Commerce Coast and Geodetic Survey 1951). The Canal is subject to considerable shoaling. The canals and locks are maintained by the Corps of Engineers.

Bridges

At the present time there are only two major bridges that cross a deep arm of Puget Sound (Fig. 1-5). These are the recently completed Tacoma Narrows and Agate Pass Bridges. The overall length of the Tacoma Narrows Bridge is 5,000 feet (2,800 feet between piers). The Agate Pass Bridge has an overall length of 1,229 feet.

Ferry boat service is the only current means of directly crossing the Sound from one populated area to the other. At least four alternate bridge routes are now being surveyed that would bridge Puget Sound in the vicinity of Seattle. The minimum distance for this connecting bridge is about two and one-half miles. With water depths averaging 800 feet for over half of the total length, the construction of a conventional type of bridge would be close to impossible. Such proposals as floating tunnels or tubes are being considered as well as a special pontoon bridge to cross the widest section. Shorter connecting links may be of the high-level suspension bridge type. The former methods would involve a considerable amount of special oceanographic research.

See Fig. 1-5 for routes of the existing and proposed bridges. Further explanation may be obtained from the literature (Andrew 1949, 1951; Hadley 1951).

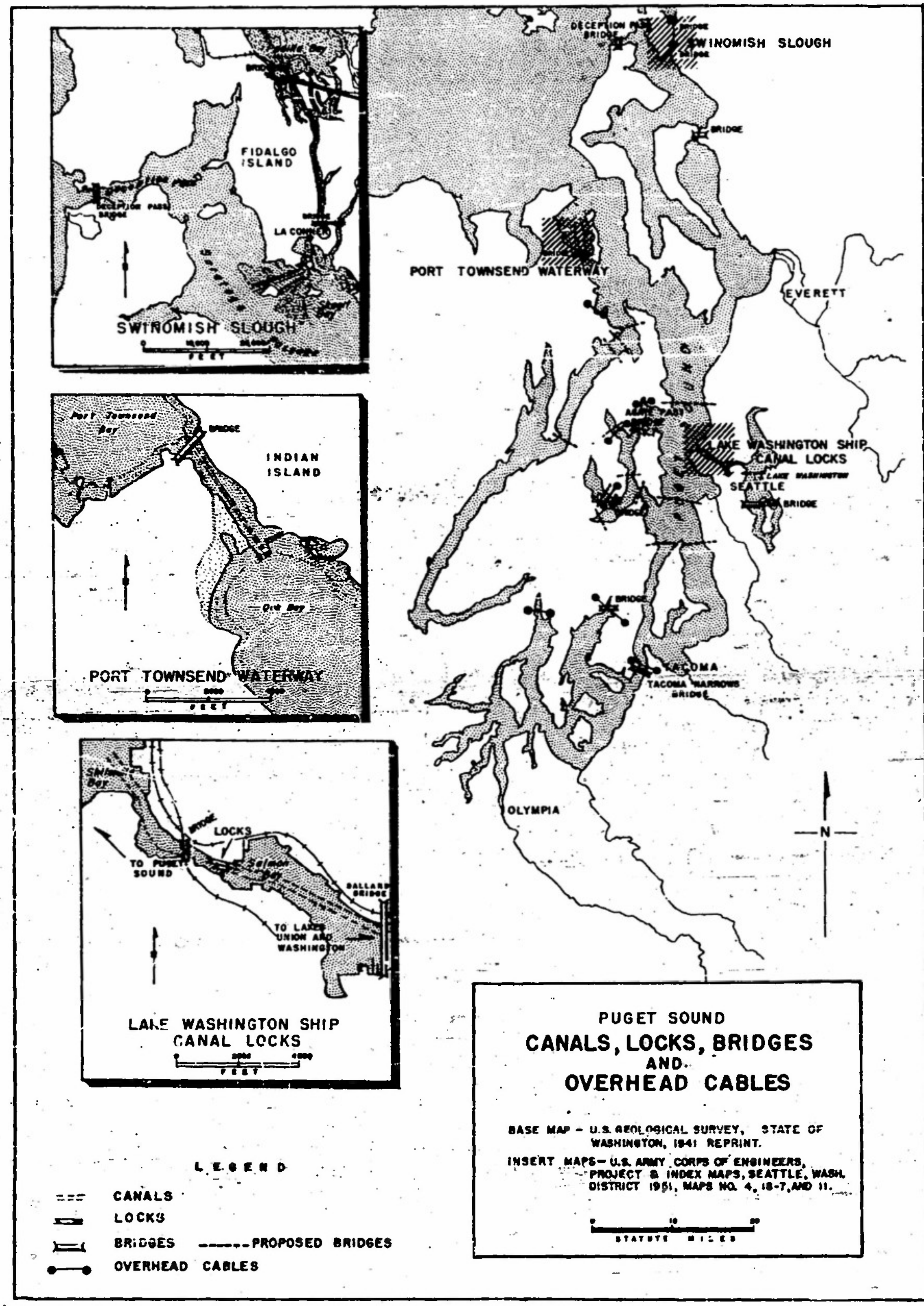

PUGET SOUND
CANALS, LOCKS, BRIDGES
AND
OVERHEAD CABLES
BASE MAP - U.S. GEOLOGICAL SURVEY, STATE OF WASHINGTON, 1941 REPRINT.
INSERT MAPS- U.S. ARMY CORPS OF ENGINEERS, PROJECT & INDEX MAPS, SEATTLE, WASH. DISTRICT 1951, MAPS NO. 4, 18-7, AND 11.
STATUTE MILES
LEGEND
CANALS
LOCKS
BRIDGES
PROPOSED BRIDGES
OVERHEAD CABLES
SWINOMISH SLOUGH
FIDALGO ISLAND
LA CONNER
PORT TOWNSEND WATERWAY
INDIAN ISLAND
BRIDGE
LAKE WASHINGTON SHIP CANAL LOCKS
LOCKS
TO PUGET SOUND
BALLARD BRIDGES
TO LAKES UNION AND WASHINGTON
FEET
DECEPTION PASS BRIDGE
EVERETT
SEATTLE
TACOMA
TACOMA NARROWS BRIDGE
OLYMPIA
N

Fig. 1-5

Appendix 1-A

PRINCIPAL BEACHES IN CENTRAL PUGET SOUND
(See Fig. 1-6)

(1) MUKILTEO

TYPE - Sandy, polluted badly from Everett; some gravel.

ACCESS - State is developing a new park in this vicinity.

(2) EDMONDS

TYPE - Mixed sand with some gravel, slope fairly steep.

ACCESS - Town of Edmonds has small undeveloped beach reaching from just south of fish or cat food cannery to dock. Some parking, no topographical problem of access. Salt marsh behind beach partly filled in.

(3) RICHMOND BEACH

TYPE - Mixed sand with some gravel, a few spots all gravel.

ACCESS - Property leased by Great Northern Railroad to local community club, has parking lot on north end, used as public beach. About 1600-3000 foot frontage. Large dune built up on southerly portion where old wooden ships have been run aground and burned. Dune 30 feet high, has more than 30-degree slope on north side. Part of beach completely covered at high tide.

(4) INNIS ARDEN (At mouth of Boeing Creek)

TYPE - Light gravel, small delta.

ACCESS - Private beach, no development except pedestrian underpass by railroad. Good road to beach level but not onto beach.

(5) CARKEEK PARK (At mouth of Piper Creek)

TYPE - Sand, with light to heavy gravel on upper strip, small sand delta. Polluted.

ACCESS - City of Seattle Park, but very little development other than road. Grade crossing of railroad.

(6) GOLDEN GARDENS (Meadow Pt.)

TYPE - Sandy with some light gravel. Beach fairly steep near point. Salt meadow.

ACCESS - City of Seattle Park, fully developed with automobile access to beach. Beach from this point south to Shilshole Bay of fair quality, road bulkheaded, some beach completely covered at high tide.

(7) SHILSHOLE BAY (Entrance to Lake Washington Ship Canal)

TYPE - Sandy for several hundred yards north of Tregoning Boat Works.

ACCESS - Access at railroad grade; not a public beach but used as such.

(8) FORT LAWTON - West Point

TYPE - Sandy, especially on south side of point, very fine level beach, steep bluffs behind.

ACCESS - Road to lighthouse via fort.

(9) MAGNOLIA - (Four Mile Rock)

TYPE - Light to heavy gravel, sand toward water, fairly narrow beach.

ACCESS - Difficult, mainly by foot. 100-foot cliff, one road via Magnolia Park.

(10) DUWAMISH HEAD TO ALKI POINT

TYPE - Sandy, some gravel, steeper toward Alki.

ACCESS - Road along complete length to lighthouse. Alki Beach (City of Seattle) on north side of point - developed.

(11) LINCOLN PARK - Pt. Williams

TYPE - Gravelly, fairly narrow, similar type carries north to Alki Point. Pt. Williams originally had a small lagoon, now a public pool.

ACCESS - Lincoln Park (City of Seattle) has service road along beach south of Pt. Williams.

(12) SEOLA - Seahurst Area

TYPE - Sandy, some light gravel.

ACCESS - At Seola, Qualheim Road follows valley to shore line, private roads only at Seahurst; steep bluffs with up to 60 per cent slope.

(13) PT. PULLY - Three Tree Pt.

TYPE - Sandy at point and south, gravel on north side, very steep bluffs.

ACCESS - By road on south, foot path on north; all property except lighthouse privately owned.

(14) NORMANDY BEACH - (At mouth of small creek)

TYPE - Sandy, with marsh behind.

ACCESS - By private road direct to private beach, partly developed.

(15) SALT WATER STATE PARK

TYPE - Mixed light to heavy gravel at upper level, sand somewhat muddy at low tide. 1300 feet of beach.

ACCESS - By good road to beach level, parking for 500 cars.

(16) REDONDO

TYPE - Light gravel similar to Lincoln Park.

ACCESS - By public road to beach level.

(17) DUMAS BAY (Small bay on East Passage)

TYPE - Sandy with marshy meadow behind.

ACCESS - Private road, very steep.

(18) PT. DEFIANCE PARK, Tacoma

TYPE - Gravel, quite steep, strong current, extremely cold (for swimming).

ACCESS - Public park, service road along east side of point, steep bluffs on west side.

(19) DOCKTON, Maury Island, Vashon Island

TYPE - Sandy, some gravel, slightly muddy in spots.

ACCESS - King County Park. Quartermaster Harbor has similar beaches, about the only area on Vashon Island with gentle slopes to beaches.

(20) AECO and ROLLS, southeasterly side of Maury Island

TYPE - Gravelly, some sand at Rosehilla, good sand at Manzanita.

ACCESS - Very steep, no roads direct to beach except at Pt. Robinson Lighthouse. Manzanita-Rosehilla Road goes to beach on west side via steep valley with one lane road.

(21) HEYER PT., Vashon Island

TYPE - Sandy, becoming gravelly toward Portage (on south). Fine protected small bay - radio tower on point.

ACCESS - Good road to beach level, undeveloped, but under consideration as public beach.

(22) ROBINSON PT., Vashon Island

TYPE - Sandy, some gravel.

ACCESS - Road to lighthouse.

(23) PARADISE COVE, Camp Sealth (Campfire Girls) to Lisabuela

TYPE - Light gravel, except in coves where creek mouths occur, some sand, somewhat steep except in coves.

ACCESS - Limited to 2-3 road ends, road into camp.

NOTE: From Burton tc Tahlequah ferry landing no roads to beach, though one or two one-land roads approach. Same true from Tahlequah west and north to Camp Sealth. Very steep bluffs subject to slide when ground cover removed.

(24) VASHON PT., Vashon Island

TYPE - Sandy

ACCESS - None by road, best sand beaches on island run from north side of point south to Biloxi and 1000 yds. or so beyond. Very steep access, no parking, limited turn-around. Road to abandoned county dock at Biloxi. All private property. Beaches south at Fern Cove are gravelly, steeper.

(25) DILWORTH, PT. BEALS, Vashon Island

TYPE - Light to heavy gravel, sand at low tide.

ACCESS - Again limited by steep topography but two private roads approach beach level. Same true north to Dolphin Pt. and around to Vashon Heights. Some kelp at Vashon Heights.

(26) PT. SOUTH, north to Manchester

TYPE - light gravel

ACCESS - Limited roads but not too steep. Navy has depot north of Manchester, also near Orchard Pt. There are some rocky areas somewhat similar to Deception Pass.

(27) PORT ORCHARD, RETSIL TO WATERMAN PT.

TYPE - Sandy to light gravel, fairly steep, would appear to be strong current, but beaches not clean, some refuse thrown back many times.

ACCESS - Road about 5 - 10 feet above high tide, follows from Bremerton to Waterman Pt.

(28) SINCLAIR INLET

TYPE - Tide flats, somewhat muddy.

ACCESS - As above.

(29) OYSTER, OSTRICH BAYS, DYES INLET, north of Bremerton

TYPE - Narrow inlets, muddy in spots, sandy with gravel at upper strip. Polluted. Northern section of Dyes Inlet - gravelly beach with mud at low tide.

ACCESS - Mostly private property, but some roads and street ends.

(30) FAY BAINBRIDGE STATE PARK

TYPE - Sandy, faces north.

ACCESS - By road to beach.

(31) ILLAHEE STATE PARK

TYPE - Mixed gravel with sand at low tide.

ACCESS - By foot to beach.

(32) INDIANOLA

TYPE - Light gravel, sand at very low tide.

ACCESS - At ferry dock only by road from very steep bluffs.

(33) POINT NO POINT, FOULWEATHER BLUFF

TYPE - Sandy, large meadow at Hansville, Point No Point.

ACCESS - Public road to beaches, which are privately owned.

(34) KINGSTON - Eagle Harbor

TYPE - Light gravel, sandy mud at low tide, large part of "Harbor" dry at low tide, used as booming ground by lumber interests.

ACCESS - Public road 5-10 feet above beach level 100 yds. north, crosses beach on west.

Table prepared by E. M. Horwood, Associate Planner, King County Planning Commission, 10 July 1952.

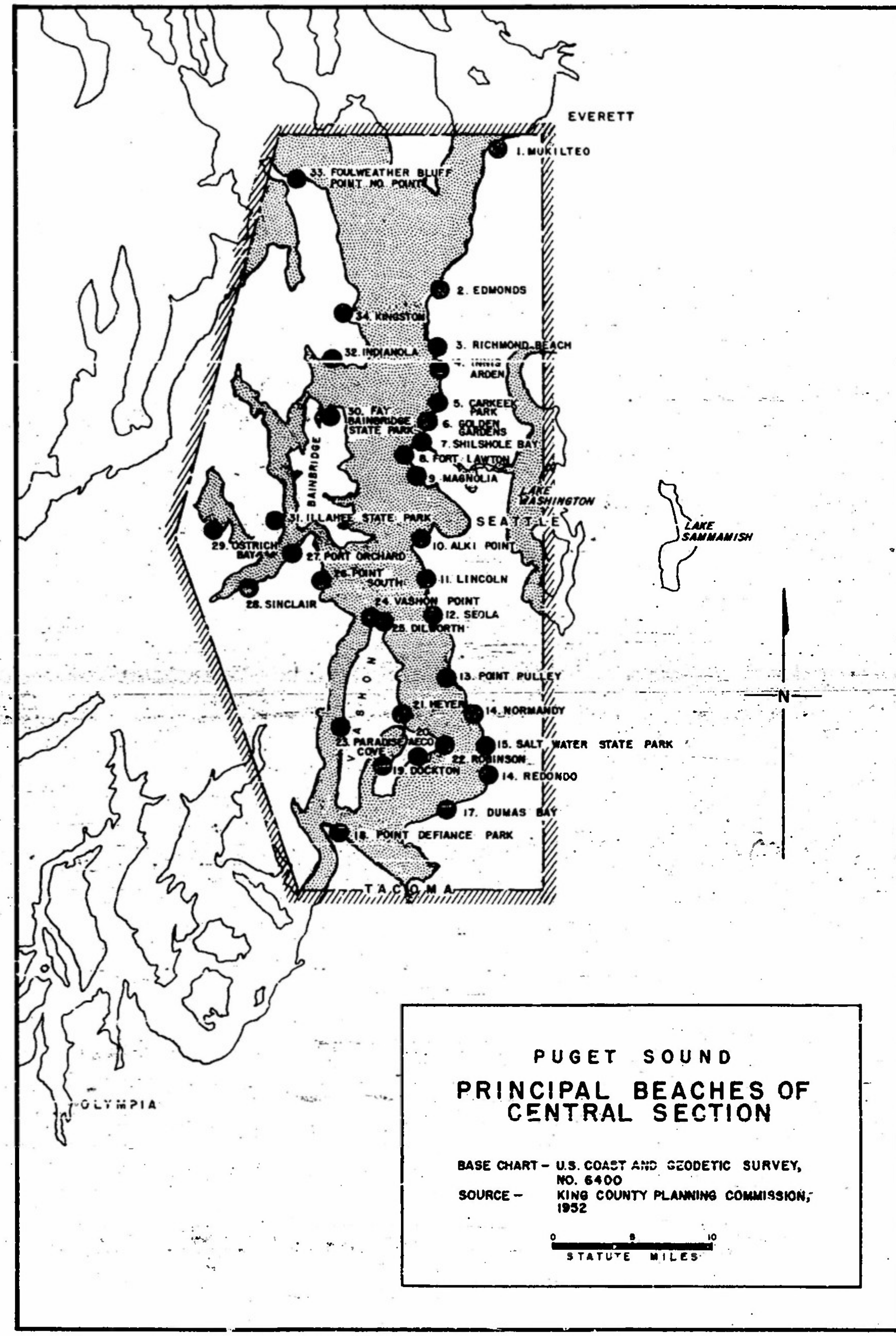

EVERETT
1. MUKILTEO
33. FOULWEATHER BLUFF
POINT NO POINT
2. EDMONDS
34. KINGSTON
3. RICHMOND BEACH
32. INDIANOLA
ARDEN
5. CARKEEK PARK
30. FAY BAINBRIDGE STATE PARK
6. GOLDEN GARDENS
7. SHILSHOLE BAY
8. FORT LAWTON
9. MAGNOLIA
BAINBRIDGE
LAKE WASHINGTON
31. ILLAHEE STATE PARK
SEATTLE
LAKE SAMMAMISH
29. OSTRICH BAY
10. ALKI POINT
27. PORT ORCHARD
11. LINCOLN
28. SINCLAIR
24. VASHON POINT
12. SEOLA
25. DILWORTH
13. POINT PULLEY
VASHON
21. HEYER
14. NORMANDY
23. PARADISE COVE
15. SALT WATER STATE PARK
22. ROBINSON
19. DOCKTON
14. REDONDO
17. DUMAS BAY
18. POINT DEFIANCE PARK
TACOMA
OLYMPIA
N
PUGET SOUND
PRINCIPAL BEACHES OF CENTRAL SECTION
BASE CHART – U.S. COAST AND GEODETIC SURVEY, NO. 6400
SOURCE – KING COUNTY PLANNING COMMISSION, 1952
0 5 10
STATUTE MILES

Fig. 1-6

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1915b. Fletcher Bay, Washington. House Document No. 426, 64th Congress, 1st Session, 4 pages.

1916. Lake Washington Ship Canal, Seattle, Washington. House Document No. 800, 64th Congress, 1st Session, 20 pages, 3 maps.

1917a. Liberty (Poulsbo or Dogfish) Bay, Washington. House Document No. 1791, 64th Congress, 2d Session, 10 pages, 1 map.

1917b. Seattle Harbor, Washington. House Document No. 54, 65th Congress, 1st Session, 8 pages, 1 map.

1922. Lake Washington Ship Canal, Washington. House Document No. 324, 67th Congress, 2d Session, 24 pages, 1 map.

U. S. Army Corps of Engineers

1928a. Bellingham Harbor, Washington. House Document No. 187, 70th Congress, 1st Session, 17 pages, 1 map.

1928b. Puget Sound and Tributary Waters, Washington. House Document No. 307, 70th Congress, 1st Session, 23 pages. (Report on preliminary examination and plan and estimate of cost of improvement of Puget Sound and Tributary waters, particularly in respect to conditions of channels and mouths of sand bars and other obstructions by use of suction dredge or otherwise.)

1930a. Duwamish Waterway, Seattle Harbor, Washington. House Document No. 126, 71st Congress, 2d Session, 20 pages, 1 map.

1930b. Everett Harbor, Washington. House Document No. 377, 71st Congress, 2d Session, 26 pages, 1 map.

1932a. East Waterway, Seattle Harbor, Washington. House Document No. 211, 72d Congress, 1st Session, 19 pages, 1 map. (Wind for Elliott Bay.)

1932b. Lake Washington Ship Canal, Washington. House Document No. 140, 27th Congress, 1st Session, 18 pages, 1 map. (Report on preliminary examination and survey of Lake Washington Ship Canal and waterway from locks to and into Lake Washington with view to widening and deepening channel.)

1932c. Port Gamble Harbor, Washington. House Document No. 152, 72d Congress, 1st Session, 15 pages, 1 map.

1932d. Tacoma Harbor, Washington. House Document No. 167, 72d Congress, 1st Session, 22 pages, 1 map.

1938. Everett Harbor, Washington. House Document No. 546, 75th Congress, 3d Session, 31 pages, 1 map.

1939. Tacoma Harbor, Washington. House Document No. 124, 76th Congress, 1st Session, 24 pages, 1 map.

1940. Olympia Harbor, Washington. House Document No. 699, 76th Congress, 3d Session, 13 pages, 1 map.

1941a. Channel from Puget Sound into Lake Crockett (Keystone Harbor), Washington. House Document No. 303, 77th Congress, 1st Session, 17 pages, 1 map.

1941b. Port Angeles Harbor, Washington. House Document No. 331, 77th Congress, 1st Session, 16 pages, 1 map. (Wind.)

U. S. Army Corps of Engineers

1941c. Port and Terminal Facilities at the Ports of Tacoma, Everett, Bellingham, Port Angeles, Olympia, and Grays Harbor, Washington. Government Printing Office, Washington, D.C., 139 pages, map, aerial photos.

1948. Appendix to Review of Reports Everett Harbor and Snohomish River, Washington. Office of the District Engineer, Seattle District, Washington, 23 pages (mimeographed). (This presents additional information to that given in the main report. Includes abstract from Geological Survey "Report Regarding the Special Discharge Measurements Made in 1943 on the Snohomish River at Everett, Washington," and an abstract from Washington Pollution Control Commission "Memorandum No. 135 Proposed Flood Control Program of Snohomish River Basin and its Effects on Fisheries of the Region.")

1950a. The Corps of Engineers in Washington. Prepared by: North Pacific Division in Cooperation with Seattle, Portland and Walla Walla Districts. (Provides a description of the major projects being undertaken in the Northwest by the U. S. Engineers.)

1950b. Everett Harbor and Snohomish River, Washington. House Document No. 569, 81st Congress, 2d Session, 31 pages, 2 maps. (Contains a review of reports of Everett Harbor and Snohomish River with two detailed charts of the docks in the harbor and river installations, wind.)

1951. Project and Index Maps. Seattle District, Seattle, Washington (processed). (For use by the Corps of Engineers. Reproduced to accompany the Annual Report of the Chief of Engineers presenting projects and their locations on reference maps. Both active and inactive projects are shown. An excellent presentation of all river and harbor, and flood control projects taking place in the Puget Sound area.)

1952a. Personal communication on Bilge Pumping Regulations and Dumping areas in Puget Sound. Letter from K. F. Smrha, Chief, Operations Division, Seattle District, to Peter McLellan, dated 26 June 1952. (No regulations in effect at this time forbidding the pumping of ship bilges into the waters of Puget Sound, as such. Mentions a special dispensation to discharge oil-bearing ballast water during the war. Oil Pollution Act of 1924 in effect. No dumping areas have been established in the waters of Puget Sound for waste matter and dredged material.)

U. S. Army Corps of Engineers
1952b. Personal communication on Location of Disposal Areas for both dredged material and refuse matter in Puget Sound. Letter from K. F. Smrha, Chief, Operations Division, Seattle District, to Frank Wang, dated 27 May 1952.
(There are no established dumping grounds in Elliott Bay and Puget Sound for the deposit of dredged materials. The quantity of material dredged has no effect on the actual sedimentation of Puget Sound.)

U. S. Army Corps of Engineers and U. S. Maritime Commission
1938a. The Ports of Everett, Bellingham, and Grays Harbor, Washington (Revised 1938). Port Series No. 28, Government Printing Office, Washington, D.C., 255 pages.
(Contains descriptions of port and harbor conditions, facilities, maps, and aerial photographs.)

1938b. The Port of Seattle, Washington (Revised 1938). Port Series No. 7, Government Printing Office, Washington, D.C., 297 pages.
(Contains descriptions of port and harbor conditions, facilities, maps and aerial photographs.)

U. S. Army Corps of Engineers and U. S. Shipping Board
1932a. The Ports of Everett, Bellingham and Grays Harbor, Washington (Revised 1931). Port Series No. 7, Part 3, Government Printing Office, Washington, D.C., 214 pages.
(Contains descriptions of port and harbor conditions, facilities, maps and aerial photographs.)

1932b. The Ports of Olympia and Port Angeles, Washington. Port Series No. 23, Government Printing Office, Washington, D.C., 125 pages.
(Contains descriptions of port and harbor conditions, facilities, maps and photographs.)

1932c. The Port of Tacoma, Washington (Revised 1931). Port Series No. 7, Part 2, Government Printing Office, Washington, D.C., 144 pages.
(Contains descriptions of port and harbor conditions, facilities, maps and aerial photographs.)

U. S. Department of Commerce Coast and Geodetic Survey
1951. United States Coast Pilot, Pacific Coast, California, Oregon, and Washington, Seventh (1951) Edition. Serial No. 750, U. S. Government Printing Office, Washington, 578 pages.
(Complete description of the Puget Sound region, including all bodies of water, harbors, points, etc.)

U. S. Department of the Interior Bonneville Power Administration
1942. Economic Atlas of the Pacific Northwest with Descriptive Text. Edited and Published by the Northwest Regional Council, Portland, Oregon, in cooperation with the Pacific Northwest Regional Planning Commission.
(Includes a discussion of climate, annual precipitation, warm season; forest types; soil areas; erosion; and population.)

1944. Pacific Northwest Opportunities. Studies of Bonneville Power Administration with Indications of Basic and Related Programs of Other Agencies, 104 pages (preliminary).
(An analysis made to serve as a basis for a full program for regional power development. Attempt to indicate the pattern of development.)

U. S. State Department
1872. Papers Relating to the Treaty of Washington. Volume V., Berlin Arbitration. Government Printing Office, Washington, 271 pages.
(Contains a series of maps drawn by Explorers showing the results of their explorations and mapping in the area now known as Puget Sound, Straits of Juan de Fuca, and Rosario Straits. These were used in the final boundary settlement. The maps sum up the entire problem of exploration and prior claim to the territory. Vertical cross sections are also given on the Parallel of 48°25', 35', 45', and 49°00'.)

Vosper, Lloyd
1947. Cruising Puget Sound and Adjacent Waters. Copyright by the Westward Press, Seattle, Washington, 88 pages.
(A general description and sketched scale charts of harbors and popular small boat anchorages of these waters, incorporating local knowledge with information of the U. S. Coast and Geodetic Survey.)

Wagner, Henry R.
1933. Spanish Explorations in the Strait of Juan de Fuca. Fine Arts Press, Santa Ana, California, 323 pages.
(Comprehensive accounts of discovery and exploration including the Puget Sound area during the latter part of the eighteenth century.)

Washington State Department of Health
1950. Bacteriological and Sanitary Survey of Oyster Bay and Eld Inlet, Thurston County, Washington. (Unpublished.)
(Report in the form of memoranda to the files. Available at the Pollution Control Commission, Olympia.)

Washington State Pollution Control Commission
1947a. Pollution Survey Data U. S. Naval Base, Bremerton, Washington, 1946-1947. (Unpublished.)
(Report in the form of memoranda to the files. Available at the Pollution Control Commission, Olympia.)

1947b. Progress Report No. 12, 37 pages (mimeographed).
(The various activities and sources contributing to the pollution of Puget Sound and adjacent areas with an analysis of each problem.)

1952. Personal communication on the Location of Sewer Outfalls in Puget Sound. Letter from Wallace W. Bergerson, Assistant Director and Associate Engineer, to Peter McLellan, dated June 13, 1952.
(Information is available on a large number of sewer outfalls entering Puget Sound, though they are not located on one map nor has any effort been made to be sure that all the outfalls are known.)

Wilkes, Charles
1845a. Narrative of the United States Exploring Expedition, During the Years 1838, 1839, 1840, 1841, 1842. London: Whittaker and Co., 367 pages.
(Includes account of Puget Sound.)

1845b. Narrative of the United States Exploring Expedition During the Years 1838, 1839, 1840, 1841, 1842. Vol. 4, chapter 12, pp. 409-440, Puget Sound and Okanogan. Philadelphia: Lea and Blanchard.
(Details of exploration in Puget Sound area.)

1858. U. S. Exploring Expedition. During the years 1838-1842. Vol. 23, Hydrography, chapter 16, Oregon Territory, pp. 303-327. C. Sherman, Printer, Philadelphia.
(An actual survey report of the entire Puget Sound area.)

Wolman, Abel
1948. City of Seattle Report on Sewage Disposal. The Johns Hopkins University, Baltimore, Md., 49 pages (mimeographed).
(Offers excellent descriptive material of Puget Sound, climate of area, and problems dealing with sewage disposal.)

SECTION 2: CLIMATOLOGY

10 February 1953

CLIMATOLOGY

INTRODUCTION

Temperate marine climate, distinguished by mild wet winters and cool dry summers, is characteristic on the Pacific Coast from northern California to southeastern Alaska. The Puget Sound Lowland has a modified form of marine climate due to the intervening topography and its distance from the Pacific Ocean.

AIR MASS CIRCULATION

Puget Sound is located in the cyclonic belt of latitude in which air flows predominantly from west to east--marine air moving inland. Gerlach (Gerlach 1938) estimates that 80 per cent of the air masses traversing the area originate at sea. The basic circulation pattern changes from winter to summer to give distinctive "wet" and "dry" seasons, but without well-defined limiting dates. The prevailing air circulation is greatly modified, both in winter and summer, by the local topography. (See Topography and Rain Shadow, and Wind, this section.)

Winter Circulation

During winter, the semi-permanent Pacific anticyclone, or "Pacific High," having a mean January pressure of 1020 millibars, centers near latitude 30° N. longitude 140° W. A more or less troughlike low pressure area, the "Aleutian Low," of about 1000 millibars in January, centers near latitude 50° N. longitude 180° W. (Landsberg 1945). This trough trends eastward paralleling the Aleutian Islands and eventually curves somewhat north of east into the Gulf of Alaska well north of the state of Washington. The frequent wintertime cyclonic disturbances of the North Pacific move along this path into the Gulf of Alaska where many of the lows stagnate. Further eastward progress is resisted by the high mountains which parallel the entire coast from the Alaskan Peninsula east then south through British Columbia and the Pacific States, and also by the mass of continental high pressure air (1020 millibars) lying eastward of the mountains.

The effect of the two maritime pressure cells and frequent cyclonic storms is to cause an almost continuous but pulsating flow of warm moist Pacific air from the southwest inland over western Washington (Donn 1951).

Summer Circulation

In summer the Pacific High intensifies, enlarges, and moves to the Northwest to center, during the period July to September, near 35° to 40° N. along the meridian of 150° W. The Aleutian Low fills in and relatively lower pressures are found northwestward over Bering Sea and Siberia. A continental low develops inland over Canada. The dominating Pacific High combined with the continental low gives a relatively weak and variable circulation with considerable flow from the northwest off the ocean coasts of Washington and Vancouver Island. This lasts from May well into September.

PRECIPITATION

The precipitation over the Puget Sound Lowland is generally a drizzle or light rain. Some rain falls almost every day during winter, but the average annual amount for the area is only 35 to 40 inches. Total precipitation for Seattle, Washington is shown in Table 2-1.

Winter Precipitation

The greatest quantity of precipitation falls in winter, with an average of about 44 per cent of the annual amount for Seattle occurring at this time. Close to three quarters of the annual amount for Seattle falls during the autumn and winter months. A list of stations with monthly and seasonal summary values is given in Table 2-2.

Early in winter the reservoirs are filled and the ground is saturated. Subsequent precipitation is either lost as immediate runoff or stored in the mountains as snow--to be lost in the spring runoff (see section on Hydrology).

Summer Precipitation

Cyclonic storms, and consequently precipitation, is infrequent during the summer. As summer approaches, evapotranspiration increases rapidly and the supply of soil moisture is rapidly depleted. At this time the region is actually deficient in available water for irrigation, power, and plant growth. Precipitation is insufficient to recharge the ground in summer because the upwind sea surface temperatures are relatively low compared to those on land causing little precipitation to be deposited by the general circulation of air which is from the northwest.

The area is thus deficient in moisture from about the middle of July until the middle of September (Thornthwaite 1948). For an analysis of the moisture data for Seattle see Table 2-3.

TABLE 2-1. Total Precipitation for Seattle, Washington.
[In Inches]

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1900	3.04	4.35	4.45	1.55	3.73	2.51	0.66	0.30	0.72	4.16	3.80	7.21	36.48
1901	4.26	4.26	1.62	3.86	1.44	1.90	0.35	0.13	2.30	1.44	6.17	2.45	30.18
1902	5.25	8.10	4.19	2.20	1.86	1.71	2.01	0.48	2.15	2.71	6.30	8.82	45.78
1903	3.12	1.45	6.10	1.56	2.39	1.55	1.28	0.50	3.18	1.94	7.34	4.14	34.55
1904	4.26	5.31	6.22	3.08	0.34	1.23	0.58	0.07	0.22	2.32	8.81	5.29	37.73
1905	5.61	2.76	3.45	1.04	3.37	3.03	0.36	0.44	1.70	4.29	2.68	5.62	34.35
1906	5.03	4.60	0.89	0.34	2.64	1.97	0.11	0.15	3.31	3.16	7.67	6.80	36.67
1907	4.18	3.87	1.12	1.54	0.98	0.78	0.71	0.80	3.39	0.67	4.73	6.33	29.10
1908	4.10	4.24	2.54	2.19	3.19	0.15	0.24	0.82	0.23	2.34	4.60	3.61	28.25
1909	6.90	4.35	1.08	0.77	1.60	0.64	0.35	0.27	1.10	2.86	9.11	2.69	31.72
1910	5.08	5.03	1.80	2.41	1.88	0.82	0.01	0.17	1.04	4.02	8.47	3.47	34.20
1911	3.67	1.42	0.88	1.21	2.48	0.44	0.18	0.13	3.27	1.00	3.26	3.75	21.69
1912	4.52	3.11	1.79	1.73	1.64	2.76	1.15	2.49	0.73	3.97	6.82	4.43	35.14
1913	4.89	1.34	1.55	0.83	1.37	1.71	0.73	0.45	2.37	2.00	4.74	2.61	24.59
1914	9.82	1.93	1.40	3.31	0.74	1.75	0.01	0.01	1.42	4.37	5.28	1.39	31.43
1915	6.35	2.76	1.72	2.91	1.72	0.40	0.84	0.05	0.65	3.00	5.66	7.77	33.83
1916	4.32	6.85	5.45	1.98	1.56	1.82	1.93	0.11	0.70	1.18	4.58	4.13	34.61
1917	2.02	1.43	2.96	4.48	0.83	3.70	0.09	0.03	1.29	0.16	2.70	9.21	28.90
1918	2.94	4.81	3.92	0.96	1.19	0.50	1.38	1.12	0.08	3.46	3.81	5.04	29.21
1919	7.95	3.77	1.84	3.20	2.08	0.35	0.22	0.08	2.03	1.59	4.13	4.10	31.34
1920	3.92	0.34	2.82	3.46	0.96	1.93	1.00	1.15	2.34	4.19	4.42	5.68	32.21
1921	5.56	4.82	3.06	1.76	1.93	1.29	0.18	1.61	1.84	3.91	6.60	7.25	39.81
1922	1.89	1.74	4.45	2.53	1.08	0.03	0.00	1.17	1.19	2.37	1.45	7.37	25.27
1923	7.51	2.72	1.37	1.67	1.45	1.01	0.68	1.98	1.37	2.05	2.06	3.31	27.18
1924	4.10	5.66	0.42	1.13	0.68	0.35	0.51	0.70	2.68	5.03	4.84	4.63	30.73
1925	4.97	4.94	1.22	2.39	1.28	0.61	0.06	1.31	0.59	0.28	3.83	4.30	25.78
1926	4.67	2.99	0.85	1.00	1.83	0.40	0.01	1.74	0.60	3.06	4.94	4.03	26.12
1927	4.95	4.68	2.69	1.58	1.81	0.37	0.10	1.03	2.73	3.85	5.86	3.33	32.98
1928	4.97	0.91	5.87	2.60	0.31	1.32	0.11	0.01	0.53	3.19	2.29	3.49	25.60
1929	2.54	1.10	2.73	1.59	1.48	1.75	0.13	1.13	0.09	1.00	1.23	5.26	20.03

(Continued on next page.)

TABLE 2-2. Rainfall Averages (Adjusted to the 30 year period 1910-1940).* [In Inches]

LOCATION	Yrs. of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average	Winter	Spring	Summer	Autumn
Aberdeen	30	13.24	9.09	8.76	5.45	3.70	2.61	1.12	1.48	3.90	7.21	11.19	13.74	81.53	36.08	17.91	5.21	22.31
Anacortes	30	3.87	2.24	2.41	1.80	1.41	1.32	0.65	0.93	1.55	2.75	3.36	4.21	26.55	10.32	5.62	2.91	7.67
Bellingham	30	4.80	3.11	2.96	2.22	1.75	1.60	0.81	1.07	1.86	3.70	4.16	5.51	33.68	13.44	6.94	3.57	9.74
Blaine	30	6.20	3.82	3.69	2.42	2.03	1.83	0.94	1.04	2.48	4.73	5.49	6.48	41.17	16.52	8.14	3.82	12.71
Bremerton	30	6.02	3.81	2.97	2.03	1.41	1.14	0.57	0.65	1.51	2.92	5.28	6.38	34.75	16.22	6.42	2.37	9.71
Coupeville	30	2.42	1.44	1.58	1.30	1.24	1.12	0.52	0.68	1.20	1.70	2.00	2.60	17.88	6.47	2.12	2.34	4.91
Cushman Dam	30	16.36	10.18	8.87	6.05	4.32	2.31	1.06	1.07	4.56	8.43	13.51	18.60	95.52	45.15	19.25	4.45	26.52
Everett	30	4.75	3.01	3.12	2.36	2.01	1.72	0.76	0.98	1.97	3.13	4.02	4.85	32.71	12.62	7.51	3.46	9.13
Friday Harbor	30	4.20	2.91	2.28	1.50	1.17	1.10	0.61	0.96	1.54	2.92	3.63	5.05	27.84	12.17	4.96	2.68	8.10
Grapeview	30	8.93	6.05	4.96	3.01	2.15	1.46	0.62	0.85	2.24	4.61	7.54	9.34	51.82	24.33	10.13	2.94	14.40
Keyport	30	5.87	3.48	2.94	1.94	1.45	1.31	0.52	0.73	1.52	2.67	4.50	6.49	33.55	15.84	6.34	2.56	8.69
Olga	30	4.39	2.59	2.47	1.72	1.28	1.29	0.71	0.86	1.69	2.95	3.85	4.92	28.77	11.91	5.48	2.87	8.49
Olympia	30	8.31	6.00	5.09	3.02	2.07	1.42	0.60	0.68	2.15	4.51	6.93	9.12	50.02	25.49	10.20	2.72	13.59
Port Angeles	30	4.15	2.67	1.83	1.12	0.90	0.80	0.45	0.61	1.28	2.24	3.16	4.59	23.82	11.41	3.85	1.86	6.69
Port Townsend	30	2.43	1.48	1.34	1.19	1.23	1.20	0.64	0.67	1.06	1.51	2.01	2.61	17.42	6.53	3.77	2.51	4.59
Quilcene	30	5.76	4.30	3.14	2.66	2.41	1.91	0.91	0.75	1.69	3.34	5.64	7.44	39.89	17.51	8.22	3.57	10.68
Seattle	30	5.14	3.56	2.95	2.15	1.46	1.32	0.57	0.78	1.50	2.89	4.34	5.54	32.21	14.24	6.57	2.67	8.74
Sedro Woolley	30	6.40	4.01	4.50	3.31	2.57	2.42	1.27	1.49	3.09	4.84	5.69	6.92	46.55	17.33	10.39	5.18	13.63
Sequim	30	2.54	1.57	1.39	1.04	0.98	0.90	0.53	0.66	1.04	1.49	2.11	3.27	17.59	7.38	3.41	2.10	4.65
Shelton	30	10.73	7.41	6.55	3.84	2.54	1.60	0.67	0.89	2.63	5.43	8.49	11.37	62.27	29.53	12.94	3.16	16.56
Tacoma	30	5.81	3.67	3.45	2.28	1.71	1.31	0.53	0.79	1.72	3.23	4.83	6.21	35.59	15.70	7.45	2.64	9.79
Tatoosh Island	30	11.25	7.94	7.71	4.92	3.25	2.70	1.56	1.90	3.96	8.40	9.91	12.09	75.61	31.28	15.88	6.16	22.28
Vancouver, B.C.	41	8.57	5.79	5.03	3.34	2.84	2.45	1.22	1.69	3.63	5.78	8.28	8.76	57.38	23.12	11.21	5.36	17.69
Vashon Island	30	6.64	4.50	3.75	2.64	1.95	1.43	0.58	0.76	1.91	3.76	5.91	7.70	41.57	18.85	8.36	2.78	11.58
Victoria, B.C.	58	4.49	3.03	2.28	1.18	0.96	0.85	0.44	0.61	1.53	2.81	4.28	4.67	27.13	13.44	6.49	2.25	4.95

*Except Canadian Stations

Table modified from Precipitation of Western Washington (Gerlach 1943), and Climatic Summaries (Canada Department of Transport Meteorological Division 1948).

TABLE 2-3. Moisture Data for Seattle, Washington. [In centimeters]

ITEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Potential Evap.	1.3	1.8	3.1	4.9	7.6	9.6	11.4	10.5	7.4	4.7	2.5	1.6	66.4
Precipitation	12.3	9.7	7.8	6.0	4.7	3.4	1.5	1.7	4.3	7.1	12.3	13.9	84.7
Storage Change	0	0	0	0	-2.9	-6.2	-0.9	0	0	2.4	7.6	0	-
Storage	10.0	10.0	10.0	10.0	7.1	0.9	0	0	0	2.4	10.0	10.0	-
Actual Evap.	1.3	1.8	3.1	4.9	7.6	9.6	2.4	1.7	4.3	4.7	2.5	1.6	45.5
Water Deficiency	0	0	0	0	0	0	9.0	8.8	3.1	0	0	0	20.9
Water Surplus	11.0	7.9	4.7	1.1	0	0	0	0	0	0	2.2	12.3	39.2
Runoff*	8.9	8.4	6.5	3.8	1.9	1.0	0.5	0.2	0.1	0.1	1.1	6.7	39.2
Moisture Ratio	8.47	4.38	1.52	0.22	-0.38	-0.65	-0.87	-0.84	-0.42	0.54	3.92	7.68	-

*Assuming that 50 per cent of the water available for runoff in any month is held over until the following month. In watersheds of less than 100 square miles the percentage is probably smaller.

Table from Thornthwaite 1948.

Topography and Rain Shadow

On land, irregular topography deflects the southwesterly flow of Pacific air both laterally and vertically, to give a myriad of local subclimates characterized by high precipitation on the windward, or southwest upslopes, and rain shadows to leeward. Precipitation amounts decrease from an estimated 200 or more inches per year [by river discharge] at the crest of the Olympic Mountains to 17.42 inches per year at Port Townsend (Gerlach 1943), just 30 miles away. East of Puget Sound the rising slopes of the Cascade range provide a mountain backdrop for a secondary belt of heavy precipitation.

It is significant that such short distances produce extreme differences in the amount of precipitation. Closely adjacent areas will be covered by rain forest vegetation while others may support only cactus and other zerophilous plants. No detailed studies or figures are available to show all the rain shadow areas which are now known only by local knowledge (see Figs. 2-1, 2-2, 2-6).

A marked decrease of precipitation from southwest to northeast through the Puget Sound Lowland is explained by the presence of the Chehalis Gap and the Olympic Mountains. The gap allows the moist Pacific southwesterly winds to enter the southern Sound country. Precipitation takes place in decreasing amounts as the air loses its moisture in passing northward. The annual precipitation at Olympia is 50.02 inches, Tacoma 35.59 inches, and Coupeville 17.88 inches (Gerlach 1943). See Table 2-2.

Rainfall Intensity

The rainfall intensity averaged from all stations on or adjacent to Puget Sound is about 0.265 inches per rainy day. The rather low figure is indicative that heavy showery rainfall is not common to the region (see Table 2-4).

THE TABLE. Intensity, or rate of rainfall, is computed on a monthly, seasonal, or annual basis as an amount of precipitation per rainy day. The precipitation intensity is computed by dividing average amounts of precipitation [adjusted] by the average number of rainy days [adjusted] in each period (Gerlach 1943).

Rainfall Probability

Probability, or frequency of occurrence of precipitation within a given period, is indicated by the average number of days in which 0.01

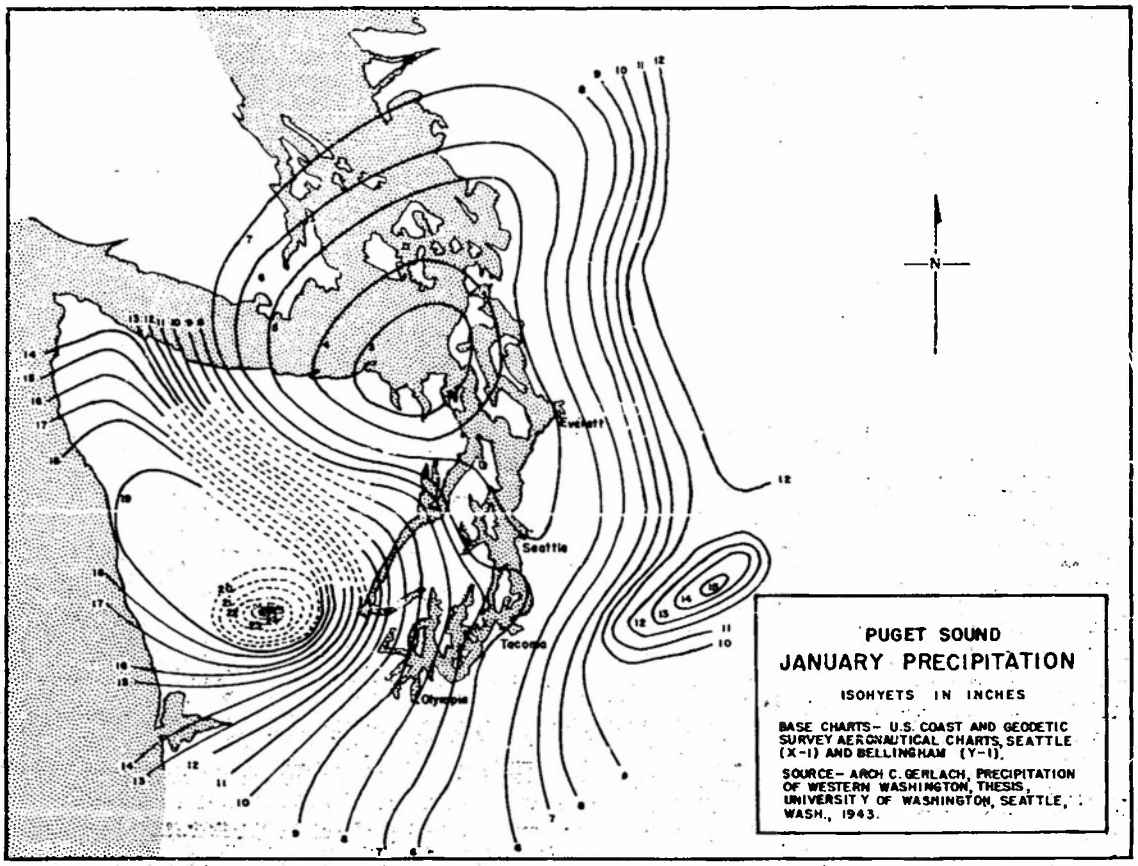
PUGET SOUND
JANUARY PRECIPITATION
ISOHYETS IN INCHES
BASE CHARTS- U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE (X-1) AND BELLINGHAM (Y-1).
SOURCE- ARCH C. GERLACH, PRECIPITATION OF WESTERN WASHINGTON, THESIS, UNIVERSITY OF WASHINGTON, SEATTLE, WASH., 1943.
Everett
Seattle
Tacoma
Olympia
N

Fig. 2-1

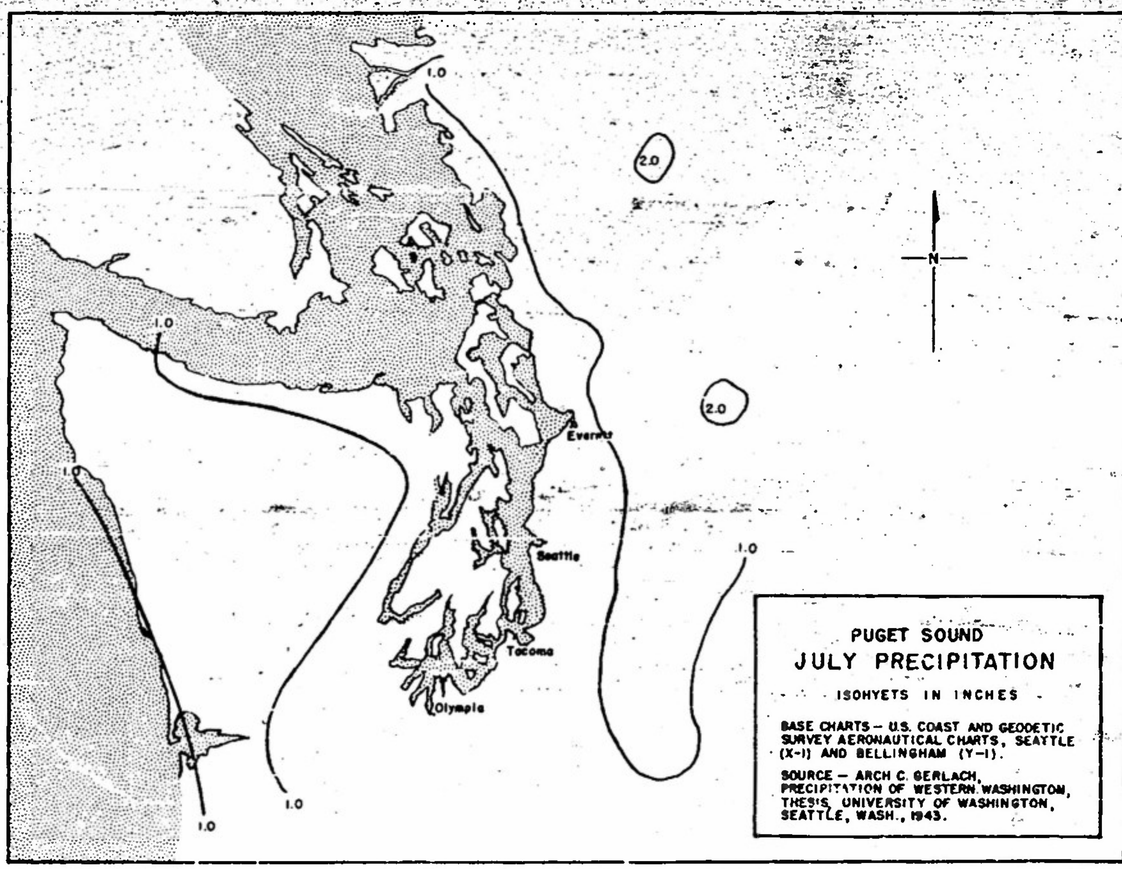
PUGET SOUND
JULY PRECIPITATION
ISOHYETS IN INCHES
BASE CHARTS – U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE (X-1) AND BELLINGHAM (Y-1).
SOURCE – ARCH C. GERLACH, PRECIPITATION OF WESTERN WASHINGTON, THESIS, UNIVERSITY OF WASHINGTON, SEATTLE, WASH., 1943.
Everett
Seattle
Tacoma
Olympia
N
1.0
2.0

Fig. 2-2

inches or more rainfall will occur. The rainfall probability averaged from all stations on or adjacent to Puget Sound is about 38.5 per cent (see Table 2-5).

THE TABLE. A comparable basis for analysis is achieved by converting the average number of rainy days into per cent of the total number in a given period. $\frac{\text{The average number of rainy days}}{\text{total days in a given period}} \times 100$ equals the average per cent of the monthly, seasonal, or annual periods during which precipitation has occurred; it also equals the per cent of these periods that rainfall is probable (Gerlach 1943).

Interpretation. This probability may be used to forecast the approximate number of days with 0.01 inches of rain or more that will occur in any given period. There is small probability of experiencing severe annual dry spells near Puget Sound, while the probability of wetter years is somewhat greater.

Snow

Occasionally the build up of air on the eastern slopes of the Cascades is sufficiently deep to allow some cold air to spill over and flood the Puget Sound Lowland. There are usually several such occurrences each winter, and each cold snap is usually preceded and ended by snowfall. This snow is not carried along with the cold continental air but is formed when the relatively warm and moist air is suddenly cooled by the intruding cold air. The snow that ends the cold snap is caused by the same process but this time the warm moist air is flowing in and either mixing with, or riding over the cold air.

The snow that precedes cold snaps remains on the ground for the duration of the low temperatures. The amount of snow falling as a result of cold continental air invasions is generally one-half to one inch. The heavy snowfalls that have occurred have been the result of cold air from Canada with a short path over water.

The maximum snowfall recorded in one month was 45 inches at the southern part of the Sound, January, 1950 (U. S. Department of Commerce Weather Bureau 1952a); 35 inches at the middle part of the Sound, February, 1916 (U. S. Department of Commerce Weather Bureau 1948); and 32.2 inches at the northern part, January, 1950 (U. S. Department of Commerce Weather Bureau 1952c). This snowfall was very unusual (see Table 2-6). For precipitation and snowfall in the mountains, see section on Hydrology.

TABLE 2-4. Rainfall Intensity [In Inches].*

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average	Winter	Spring	Summer	Autumn
Aberdeen	0.652	0.553	0.493	0.387	0.332	0.294	0.214	0.272	0.395	0.517	0.618	0.667	0.504	0.624	0.404	0.260	0.510
Anacortes	0.233	0.196	0.170	0.176	0.176	0.203	0.185	0.231	0.198	0.243	0.227	0.253	0.212	0.227	0.174	0.206	0.223
Bellingham	0.271	0.230	0.191	0.187	0.172	0.187	0.169	0.212	0.229	0.270	0.242	0.268	0.228	0.256	0.183	0.189	0.247
Blaine	0.352	0.304	0.255	0.230	0.214	0.235	0.189	0.231	0.255	0.331	0.324	0.329	0.289	0.328	0.233	0.218	0.303
Bremerton	0.315	0.253	0.198	0.170	0.146	0.175	0.181	0.151	0.190	0.233	0.335	0.338	0.248	0.302	0.171	0.169	0.253
Coupeville	0.154	0.128	0.130	0.124	0.145	0.149	0.116	0.151	0.155	0.167	0.136	0.156	0.144	0.146	0.133	0.139	0.153
Cushman Dam	0.811	0.635	0.528	0.413	0.434	0.284	0.194	0.209	0.507	0.574	0.703	0.883	0.595	0.776	0.458	0.229	0.595
Everett	0.228	0.186	0.183	0.177	0.176	0.174	0.149	0.181	0.206	0.210	0.216	0.232	0.199	0.215	0.179	0.168	0.211
Friday Harbor	0.241	0.235	0.160	0.148	0.156	0.173	0.166	0.230	0.149	0.200	0.199	0.246	0.199	0.241	0.155	0.190	0.183
Grapeview	0.520	0.419	0.329	0.255	0.218	0.210	0.206	0.223	0.302	0.377	0.459	0.507	0.379	0.482	0.267	0.213	0.379
Keyport	0.374	0.300	0.201	0.189	0.163	0.204	0.160	0.282	0.249	0.261	0.326	0.379	0.275	0.351	0.184	0.215	0.279
Olga	0.281	0.236	0.197	0.177	0.168	0.190	0.156	0.173	0.235	0.246	0.265	0.318	0.235	0.278	0.181	0.173	0.249
Olympia	0.444	0.402	0.309	0.232	0.208	0.203	0.184	0.190	0.269	0.381	0.420	0.464	0.349	0.437	0.250	0.192	0.357
Port Angeles	0.233	0.210	0.136	0.107	0.119	0.126	0.118	0.133	0.172	0.188	0.198	0.245	0.182	0.229	0.121	0.126	0.186
Port Townsend	0.169	0.158	0.142	0.134	0.180	0.179	0.175	0.184	0.190	0.174	0.180	0.190	0.170	0.172	0.152	0.179	0.181
Quilcene	0.312	0.295	0.185	0.196	0.200	0.190	0.151	0.146	0.222	0.299	0.382	0.402	0.268	0.336	0.194	0.162	0.301
Seattle	0.290	0.252	0.195	0.187	0.149	0.161	0.150	0.213	0.194	0.243	0.282	0.305	0.235	0.282	0.177	0.175	0.240
Sedro Woolley	0.322	0.257	0.262	0.246	0.221	0.257	0.248	0.275	0.330	0.353	0.304	0.331	0.290	0.303	0.243	0.260	0.329
Sequim	0.160	0.167	0.142	0.122	0.146	0.154	0.150	0.144	0.156	0.158	0.149	0.208	0.159	0.178	0.137	0.149	0.154
Shelton	0.523	0.434	0.403	0.265	0.209	0.190	0.176	0.212	0.300	0.392	0.461	0.545	0.392	0.501	0.292	0.193	0.384
Tacoma	0.317	0.245	0.211	0.181	0.154	0.165	0.141	0.185	0.218	0.255	0.295	0.324	0.244	0.295	0.182	0.164	0.256
Tatoosh Island	0.499	0.458	0.379	0.283	0.230	0.222	0.154	0.208	0.349	0.496	0.479	0.527	0.388	0.495	0.297	0.195	0.441
Vashon Island	0.408	0.344	0.283	0.251	0.217	0.240	0.198	0.219	0.273	0.323	0.404	0.442	0.332	0.398	0.250	0.219	0.333

*For explanation of table, see text.

Table modified from Precipitation of Western Washington (Gerlach 1943).

TABLE 2-5. Rainfall Probability [In Per cent]*

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average	Winter	Spring	Summer	Autumn
Aberdeen	65.43	58.68	57.31	46.89	35.91	29.56	16.90	17.50	32.89	44.94	60.33	56.45	44.30	63.52	46.70	21.33	46.05
Anacortes	53.57	40.81	45.73	34.05	25.81	21.72	11.40	13.00	26.09	36.59	49.33	53.61	34.27	49.33	35.20	15.37	37.34
Bellingham	57.00	48.32	49.94	39.54	32.90	29.88	15.51	16.31	27.14	44.18	57.29	66.21	40.30	57.18	40.80	20.57	42.87
Blaine	56.77	44.86	46.55	34.96	30.57	25.86	16.07	14.60	32.44	46.02	56.41	63.44	39.01	55.02	37.36	18.84	44.96
Bremerton	61.48	53.81	48.38	39.80	31.18	21.76	10.21	14.30	26.48	40.32	52.59	60.90	38.32	58.73	39.79	15.42	39.80
Coupeville	50.80	40.18	39.17	34.82	27.71	25.09	14.58	14.68	25.87	32.85	49.00	53.65	33.98	48.21	33.90	18.12	35.91
Cushman Dam	65.10	57.29	54.17	48.82	32.10	27.16	17.70	16.53	29.98	47.41	64.06	67.95	43.93	63.45	45.03	20.46	47.15
Everett	67.05	57.85	56.51	44.53	36.83	32.81	16.57	17.50	31.86	48.00	61.99	67.31	44.81	64.07	45.96	22.29	47.28
Friday Harbor	56.21	44.25	45.91	33.84	24.22	21.23	11.89	13.50	24.27	47.03	60.60	66.21	38.22	55.56	34.66	15.54	43.97
Grapeview	55.40	51.47	48.60	39.33	31.72	23.22	9.78	12.25	24.77	39.35	54.67	59.46	37.41	55.44	39.86	15.08	39.60
Keyport	50.53	41.32	47.31	34.09	28.72	21.36	10.56	12.90	20.32	33.02	46.00	55.16	33.41	49.00	36.71	14.94	33.11
Olga	50.40	39.28	40.50	32.33	24.51	22.67	14.62	16.13	24.00	38.60	48.33	49.89	33.40	46.52	32.45	17.81	36.98
Olympia	60.30	53.84	53.04	43.33	32.14	23.33	10.60	11.63	26.67	38.13	54.88	63.40	39.17	59.18	42.84	15.18	39.89
Port Angeles	57.40	45.34	43.40	34.92	24.12	21.11	12.20	14.72	24.93	38.29	53.04	60.30	45.75	54.35	34.15	16.01	38.75
Port Townsend	46.23	33.45	30.43	29.56	22.15	22.44	11.83	11.72	18.67	28.06	37.11	44.30	27.96	41.33	27.38	15.33	27.95
Quilcene	59.50	52.01	54.70	45.26	38.85	33.49	19.36	16.52	25.33	36.00	49.14	59.69	40.75	57.06	46.27	23.12	36.82
Seattle	57.07	50.43	48.81	38.35	31.73	27.30	12.24	11.80	25.72	38.24	51.22	58.54	37.53	55.34	39.63	17.11	38.39
Sedro Woolley	64.00	55.60	55.40	44.89	37.41	31.33	16.56	17.46	31.22	44.19	62.30	67.31	43.89	62.32	45.90	21.78	45.90
Sequim	51.00	33.62	31.55	28.16	21.73	19.51	11.47	14.76	22.23	30.39	47.27	50.64	30.17	45.08	27.14	15.24	33.29
Shelton	66.20	60.96	52.40	48.32	39.20	28.06	12.23	13.54	29.17	44.71	61.36	67.33	43.49	64.83	46.64	17.94	45.08
Tacoma	59.01	53.43	52.80	41.92	35.60	26.42	12.19	13.86	26.29	40.74	54.57	61.76	39.80	58.07	43.44	17.49	40.53
Tatoosh Island	72.70	61.90	65.50	57.90	45.40	40.49	32.61	29.51	37.78	54.60	68.89	73.95	53.38	69.52	56.27	34.20	53.76
Vashon Island	52.41	46.69	42.71	35.12	29.03	19.88	9.56	11.23	23.33	37.51	48.72	56.15	34.29	51.75	35.62	13.56	36.52

*For explanation of table, see text.

Table modified from Precipitation of Western Washington (Gerlach 1943).

TABLE 2-6. Average Monthly and Annual Snowfall with Variability [In Inches].

LOCATION	Yrs.of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average	Standard Deviations Yrs.of Record	Average	Variability	Per cent Variability
Aberdeen	36	6.3	4.2	0.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.1	14.9	21	10.3	11.3	110
Anacortes	36	2.6	2.0	0.5	T	.0	.0	.0	.0	.0	.0	0.5	0.8	6.4	21	3.0	3.8	126
Bellingham	18	5.8	2.5	1.0	T	.0	.0	.0	.0	.0	.0	0.9	1.5	10.7	22	11.1	9.0	81
Blaine	31	5.1	3.2	2.0	T	.0	.0	.0	.0	.0	T	1.3	2.6	14.2	22	11.1	9.1	81
Bremerton	15	3.8	1.6	0.8	0.1	.0	.0	.0	.0	.0	.0	0.7	2.9	9.9	20	7.8	7.8	100
Coupeville	28	3.1	2.0	1.1	0.1	.0	.0	.0	.0	.0	.0	0.5	1.0	7.8	19	4.1	5.0	121
Cushman Dam	6	11.3	1.8	2.0	0.1	.0	.0	.0	.0	.0	.0	1.9	9.6	26.7	11	41.0	32.9	80
Everett	16	4.9	2.3	0.5	0.3	.0	.0	.0	.0	.0	.0	0.1	2.7	10.8	21	11.7	11.1	94
Grapeview	22	3.7	2.7	T	0.1	.0	.0	.0	.0	.0	.0	0.2	1.6	8.3	19	6.0	6.4	104
Keyport	12	1.7	3.9	T	.0	.0	.0	.0	.0	.0	.0	T	1.6	7.2	17	3.29	11.3	343
Olga	37	3.2	3.1	1.0	0.1	T	.0	.0	.0	.0	T	0.7	0.9	9.0	13	6.84	3.6	52
Olympia	34	6.4	2.7	0.3	0.1	T	.0	.0	.0	.0	T	0.6	1.5	11.6	24	11.12	9.2	82
Port Angeles	28	2.7	3.4	0.8	T	.0	.0	.0	.0	.0	T	0.6	2.6	10.1	5	9.8	4.3	43
Port Townsend	36	3.5	3.0	0.5	T	.0	.0	.0	.0	.0	T	0.3	1.2	8.5	23	7.0	11.2	160
Quilcene	1	3.6	3.0	0.6	0.2	.0	.0	.0	.0	.0	.0	0.4	2.5	10.3	17	8.2	9.2	112
Seattle	40	5.2	4.3	1.0	0.2	T	.0	.0	.0	.0	T	1.0	2.0	13.7	20	5.35	8.0	149
Sedro Woolley	31	4.2	2.4	1.0	T	.0	.0	.0	.0	.0	.0	0.6	1.0	9.2	20	3.6	3.8	105
Sequim	13	1.7	1.8	0.1	0.1	.0	.0	.0	.0	.0	.0	0.8	3.4	7.9	20	7.0	8.7	124
Tacoma	33	6.2	3.8	0.8	0.2	.0	.0	.0	.0	.0	.0	0.9	2.0	13.9	17	10.7	9.8	91
Tatoosh Island	41	3.7	2.5	0.8	0.3	.0	.0	.0	.0	.0	.0	0.4	0.7	8.4	-	-	-	-
Vashon Island	34	4.5	2.4	0.5	0.1	.0	.0	.0	.0	.0	T	0.7	1.0	9.2	-	-	-	-

T = Trace

Table modified from Climatic Summary of the United States (U. S. Department of Agriculture Weather Bureau 1936), and Type Curves and Variability of Annual Snowfall (Church 1941).

Variability. The snowfall variability is extremely significant in this area. Some years there may be no snow at some stations while the same stations may record as high as 20 inches the following year. Of fifty-three winters, six have had only traces of snow, while the winter of 1915-16 had about 30 inches as averaged for the representative stations in the area (see section on Hydrology, Table 3-2).

TEMPERATURE

The mean annual temperature on or near Puget Sound is about 50° F. Intense heat and cold waves are unknown in the Puget Sound Lowland. The Cascade Mountains effectively block the westward spread of warm air during summer and cold air during winter (see Figs. 2-3, 2-4, 2-5). Average temperatures for Seattle, Washington, are shown in Table 2-7.

The coldest temperatures recorded in the Puget Sound Lowland range from -3° to 14° F. with the average minimum for all stations being 3° F. The mean January temperature is about 38° F. Cold snaps are usually of short duration lasting from five to ten days and accompanied by clean air with east to northeast winds. In winter the center section of the Puget Sound Lowland, with Seattle as the focal point, is the warmest with lower temperatures both to the north and south.

The highest temperatures recorded range from 88° to 105° F. with the average maximum being about 96° F. On the east shore of the Puget Sound the average temperature for the warmest month varies from 64° F. on the south, to 61° F. on the north, with an average daily range of 18° to 27° F. according to specific locality (see Table 2-8).

On clear calm nights the valleys within the city of Seattle have shown temperatures 16° F. cooler than nearby hilltops. On cloudy nights back radiation is trapped by the clouds causing little temperature variation throughout the city, especially if there is a slight wind to mix the air.

HUMIDITY

The average daily relative humidity for the different sections of Puget Sound are: Olympia, 80 per cent; Tacoma, 76 per cent; Seattle, 76 per cent; Port Angeles, 84 per cent; and Tatoosh Island, 88 per cent. Readings are made at 5 a.m., noon, and 5 p.m. (Pacific Standard Time). The 5 a.m. readings are the highest throughout the region (U. S. Department of Agriculture Weather Bureau 1936).

TABLE 2-7. Average Temperatures for Seattle, Washington.
[In Degrees Fahrenheit]

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1900	43.8	42.3	49.9	51.8	56.0	61.9	65.0	62.6	58.6	51.8	44.4	45.8	52.8
1901	40.2	42.9	46.0	47.8	55.4	57.1	61.6	65.7	58.0	57.2	49.2	42.4	52.0
1902	39.8	46.4	45.0	50.0	56.5	60.6	63.8	64.4	58.4	54.3	45.8	41.8	52.2
1903	42.9	40.2	42.5	47.9	54.6	61.9	61.9	63.2	57.7	53.6	46.0	42.6	51.2
1904	41.8	40.2	42.6	52.6	55.1	59.7	64.2	63.6	61.0	54.2	49.4	43.9	52.4
1905	40.8	43.3	49.8	52.7	54.5	59.2	64.6	62.6	59.4	48.6	45.2	42.6	51.9
1906	42.4	43.8	45.5	53.0	54.6	58.0	67.7	65.0	58.9	54.0	45.2	42.4	52.5
1907	33.8	41.8	43.2	49.1	57.0	59.4	64.2	61.3	58.6	53.2	48.0	43.4	51.1
1908	41.8	41.7	44.2	49.0	51.6	58.8	65.1	62.2	57.1	50.8	48.8	39.5	50.9
1909	34.2	42.0	44.1	47.7	52.3	59.4	60.6	61.6	60.1	52.2	45.5	36.4	49.7
1910	39.0	38.3	47.6	49.4	57.0	57.5	62.6	60.2	58.0	52.8	45.5	42.8	50.9
1911	38.0	39.8	45.8	46.6	52.7	57.0	65.0	62.6	57.1	52.5	44.7	41.2	50.2
1912	42.6	43.9	44.3	48.0	57.0	60.0	63.4	62.2	59.2	49.9	46.2	41.6	51.5
1913	36.6	40.0	41.9	49.0	54.1	59.5	63.4	64.8	58.8	50.1	46.2	42.4	50.6
1914	43.2	42.3	47.6	51.4	57.3	58.9	64.2	63.2	56.7	54.6	47.2	39.7	52.2
1915	40.6	44.5	50.0	52.6	56.0	59.8	64.3	66.8	59.1	53.7	43.7	42.0	52.8
1916	31.0	41.9	44.4	49.0	52.0	58.8	61.1	63.6	58.8	49.1	43.0	38.0	49.2
1917	38.0	39.3	41.0	46.8	52.4	57.2	63.4	65.2	58.9	52.5	49.6	45.0	50.8
1918	43.7	40.0	44.0	50.0	52.4	61.6	63.0	62.6	62.2	53.4	45.8	40.9	51.6
1919	41.4	40.8	44.7	49.6	53.6	57.5	63.0	63.0	59.6	48.5	44.9	38.6	50.4
1920	40.2	40.3	44.4	45.6	51.6	58.6	64.2	64.4	57.8	50.1	47.0	43.4	50.6
1921	40.4	42.9	44.6	47.5	53.6	59.8	60.8	62.0	57.0	53.2	45.4	39.1	50.5
1922	35.5	39.4	41.5	46.6	54.5	60.8	62.9	62.7	59.8	53.5	43.6	38.4	49.9
1923	40.4	37.3	44.0	51.0	54.1	60.6	64.4	65.7	60.8	54.6	47.4	42.2	51.9
1924	41.0	46.0	44.4	49.0	57.4	59.9	63.5	62.4	59.5	52.8	44.6	37.2	51.5
1925	42.6	45.6	44.9	50.6	57.8	60.1	65.0	62.6	59.5	51.4	46.0	45.6	52.6
1926	42.0	46.8	50.4	55.8	56.4	62.8	66.0	64.1	58.0	55.0	49.4	41.6	54.0
1927	40.6	43.9	43.8	48.7	52.4	61.5	65.2	65.0	58.7	53.2	46.5	38.0	51.5
1928	42.3	43.2	48.2	48.8	58.2	59.5	65.0	63.0	58.4	51.8	46.8	41.4	52.2
1929	34.6	36.2	45.0	46.7	54.6	59.2	64.3	64.8	60.8	55.6	45.2	43.6	50.9

(Continued on next page.)

TABLE 2-7. Average Temperatures for Seattle, Washington (continued).
[In Degrees Fahrenheit]

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1930	32.8	44.3	46.8	52.8	53.4	58.8	63.0	65.3	59.4	51.0	44.8	43.1	51.3
1931	45.7	44.4	47.1	52.6	58.5	59.6	65.2	64.2	59.2	52.5	43.2	41.8	52.8
1932	38.8	40.9	46.4	50.7	54.8	61.8	61.1	63.2	60.5	54.1	48.8	38.8	51.7
1933	39.6	37.5	45.0	49.4	53.4	60.2	64.2	66.8	57.6	54.0	46.8	45.1	51.6
1934	45.6	48.7	52.0	56.4	58.8	62.2	63.9	66.2	59.5	55.2	50.0	44.0	55.2
1935	41.6	45.0	43.6	50.7	56.6	61.6	64.9	64.7	62.7	51.4	43.5	45.0	52.6
1936	44.2	36.3	44.0	53.8	59.0	63.2	65.9	66.4	59.6	55.9	46.0	44.0	53.2
1937	31.7	41.4	48.9	49.2	56.7	63.0	65.8	64.4	61.0	56.7	48.8	44.9	52.7
1938	42.5	44.4	46.4	53.4	57.8	62.7	67.3	63.3	63.4	55.0	45.4	44.0	53.8
1939	44.7	40.6	46.4	53.6	57.6	59.8	65.9	66.6	61.1	54.2	51.0	47.5	54.1
1940	45.4	47.0	50.7	54.1	60.4	64.4	66.0	66.4	64.0	57.1	44.6	46.4	55.5
1941	45.9	48.2	53.1	55.0	57.6	62.2	69.6	65.5	58.9	54.6	49.1	43.9	55.3
1942	42.8	44.0	46.8	52.7	56.6	60.7	67.7	67.7	61.4	55.4	45.6	44.4	53.8
1943	36.4	45.2	45.5	53.6	54.6	60.0	64.3	63.9	63.4	54.3	48.4	43.0	52.7
1944	44.2	43.8	45.9	51.8	57.0	60.8	65.4	64.5	63.1	57.5	47.8	41.9	53.6
1945	44.5	44.7	45.6	48.8	58.8	60.6	66.6	64.8	59.4	54.8	46.2	43.0	53.2
1946	43.2	44.4	46.1	51.0	59.9	60.4	66.5	65.0	60.6	51.1	44.3	41.8	52.9
1947	38.8	46.8	50.1	54.1	60.4	61.6	65.6	64.2	61.0	54.5	45.9	45.1	54.0
1948	41.4	41.9	45.2	48.0	55.0	63.8	64.4	63.0	59.6	52.4	45.0	39.0	51.6
1949	33.6	39.8	47.5	51.8	59.1	60.8	63.4	64.6	62.6	51.0	51.5	41.8	52.3
1950	28.8	43.2	44.8	49.7	54.1	61.9	65.7	66.1	61.0	52.5	46.8	48.0	51.9
1951	40.3	44.0	42.6	53.5	57.0	63.8	66.5	64.3	61.9	53.6	47.7	39.9	52.9

Table from U. S. Department of Commerce Weather Bureau 1952f.

The atmosphere over the Puget Sound Lowland is naturally moist due to its proximity to the sea and the frequency of storms in the winter. Stations nearest tidewater show the highest average relative humidity. A combination of high temperature and high humidity is almost unknown-- the warmest parts of the warmest days being very dry, hence the sensation of sultriness is rarely experienced. The dampness in winter gives an increased sensation of coolness. Periods of unusually low humidity accompany east and northeast winds, particularly those blowing from areas of high barometric pressure in the interior, and which continue very dry after crossing the mountains because of dynamic compression and warming as they pass down the mountain slopes. Occasionally in spring and autumn, and more frequently in summer, they cause periods of high flammability (U. S. Department of Agriculture Weather Bureau 1936). For relationship between humidity and haze or visibility, see Atmospheric Pollution.

WIND

The highest wind velocities recorded in major cities by Puget Sound are 61 miles per hour (for a one-minute period) from the south at Tacoma in December 1940 (U. S. Department of Commerce Weather Bureau (1952b); and 60 mph** (for a five-minute period) from the south at Seattle in April 1943 (U. S. Department of Commerce Weather Bureau 1948). The highest wind velocity of the region, 94 mph, was recorded at Tatoosh Island in November 1942 (U. S. Department of Commerce Weather Bureau 1952c). See Table 2-10. Tatoosh Island is located seaward of Puget Sound on the northwestern tip of the state where the ocean meets the Strait of Juan de Fuca.

Locally, topography and proximity to the ocean influence both the direction and force of the prevailing southwest and west winds (see Table 2-11). Winds tend to funnel up and down the long axes of valleys and marine channels, persisting whether they are along or athwart the general circulation pattern, although stronger in the former case. Many stations have winds from a northerly quarter during winter. When the area of high pressure is centered east of the Cascades the wind may blow out of the Strait of Juan de Fuca with gale force following the east-west trend of the Strait. Under these same conditions the winds along the north-south axis on Puget Sound proper are light and variable. Winds which reach hurricane force along the coast, only 45 miles from Olympia, will reach only 50 to 55 mph in gusts in the vicinity of Olympia (U. S. Department of Commerce Weather Bureau 1952a). See Tables 2-9, 2-10, 2-11, and Fig. 2-7.

**Anemometer in Exchange Building, Seattle, Wash.; elevation: 349 feet.

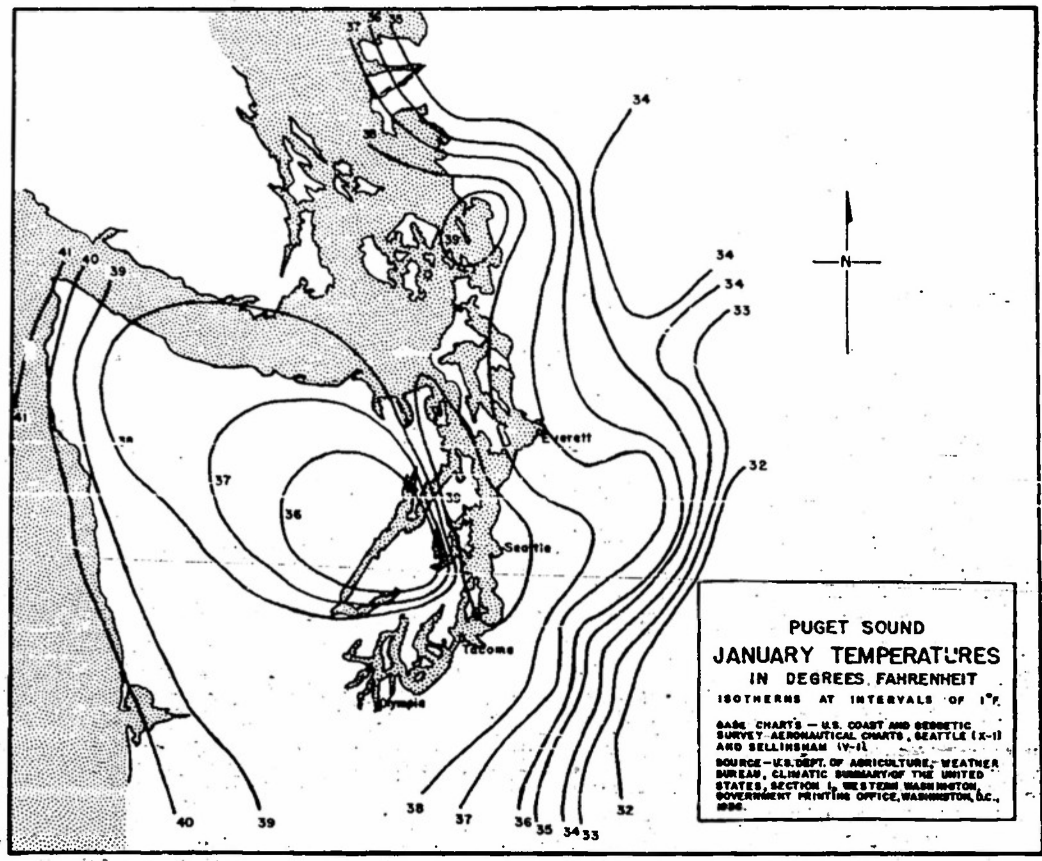
PUGET SOUND
JANUARY TEMPERATURES
IN DEGREES FAHRENHEIT
ISOTHERMS AT INTERVALS OF 1°F.
BASE CHARTS — U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE (X-1) AND BELLINGHAM (V-1)
SOURCE — U.S. DEPT. OF AGRICULTURE, WEATHER BUREAU, CLIMATIC SUMMARY OF THE UNITED STATES, SECTION 1, WESTERN WASHINGTON, GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.,
N
Everett
Seattle
Tacoma
Olympia

Fig. 2-3

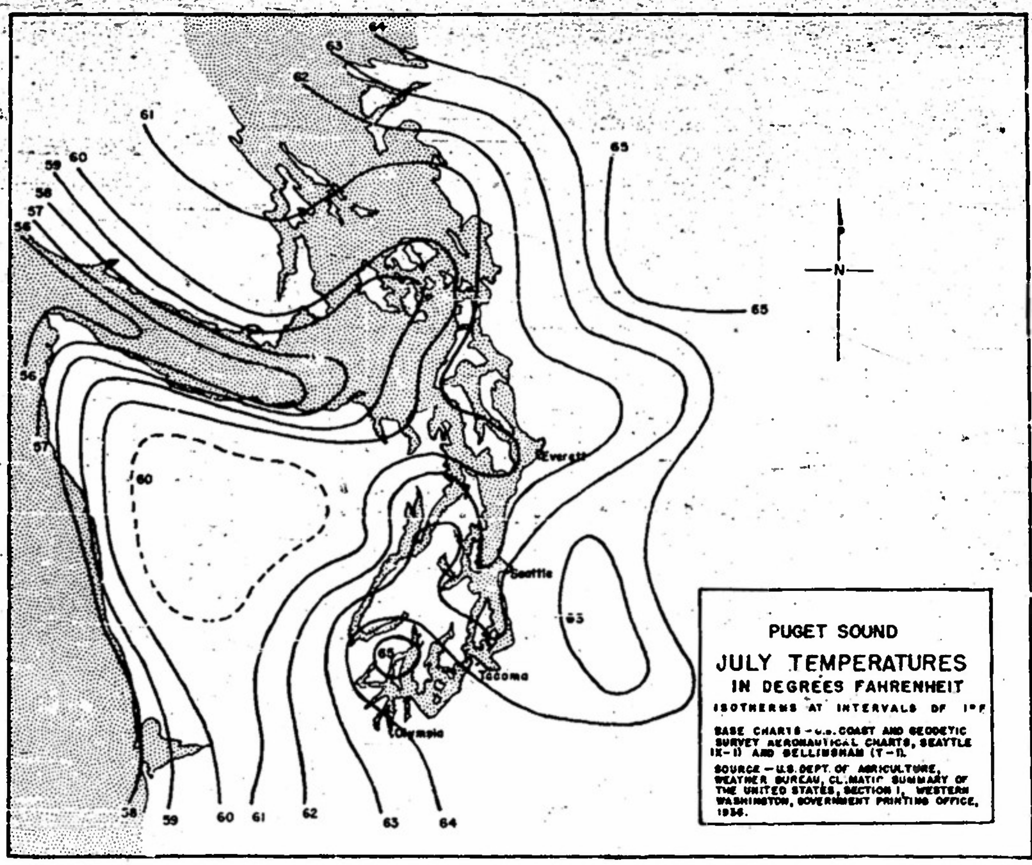
PUGET SOUND
JULY TEMPERATURES
IN DEGREES FAHRENHEIT
ISOTHERMS AT INTERVALS OF 1°F
BASE CHARTS — U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE (X-1) AND BELLINGHAM (T-1).
SOURCE — U.S. DEPT. OF AGRICULTURE, WEATHER BUREAU, CLIMATIC SUMMARY OF THE UNITED STATES, SECTION 1, WESTERN WASHINGTON, GOVERNMENT PRINTING OFFICE, 1936.
N
Everett
Seattle
Tacoma
Olympia

Fig. 2-4

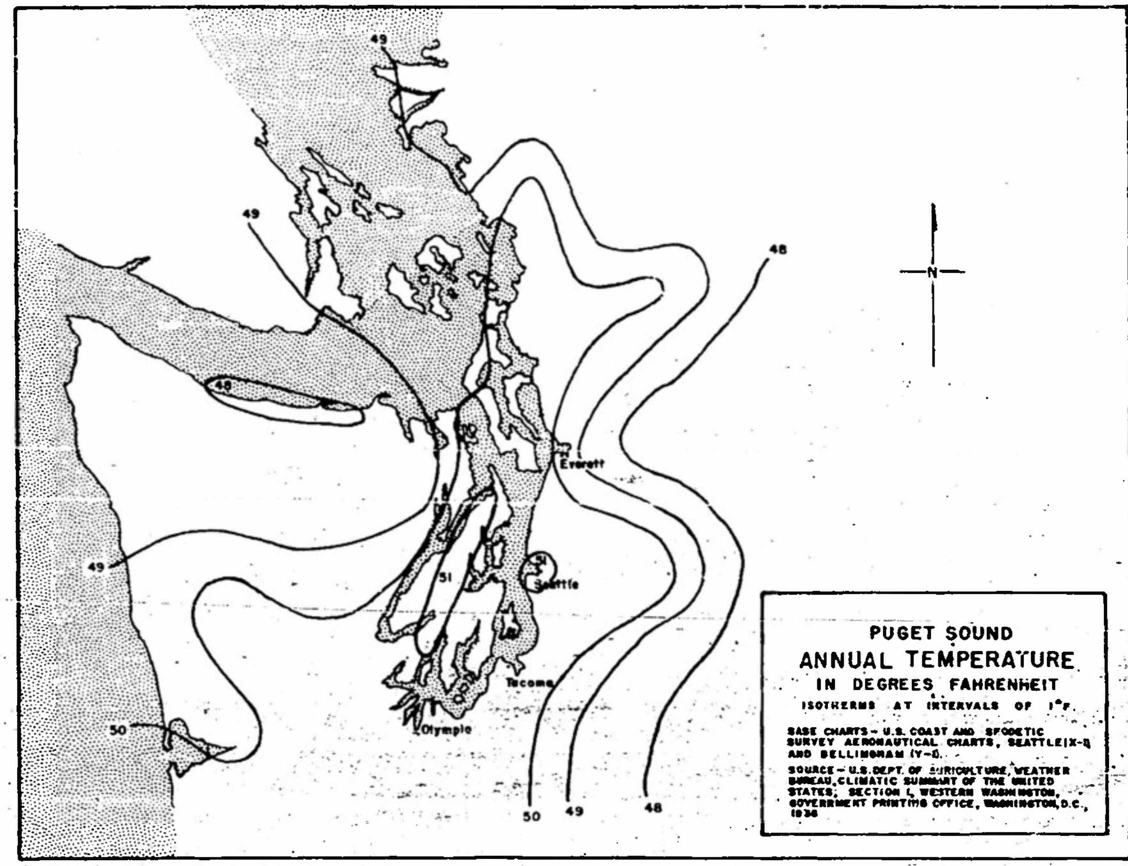
N
Everett
Seattle
Tacoma
Olympia
PUGET SOUND
ANNUAL TEMPERATURE
IN DEGREES FAHRENHEIT
ISOTHERMS AT INTERVALS OF 1°F.
BASE CHARTS – U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE (X-1) AND BELLINGHAM (Y-1).
SOURCE – U.S. DEPT. OF AGRICULTURE, WEATHER BUREAU, CLIMATIC SUMMARY OF THE UNITED STATES; SECTION 1, WESTERN WASHINGTON, GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C., 1936

Fig. 2-5

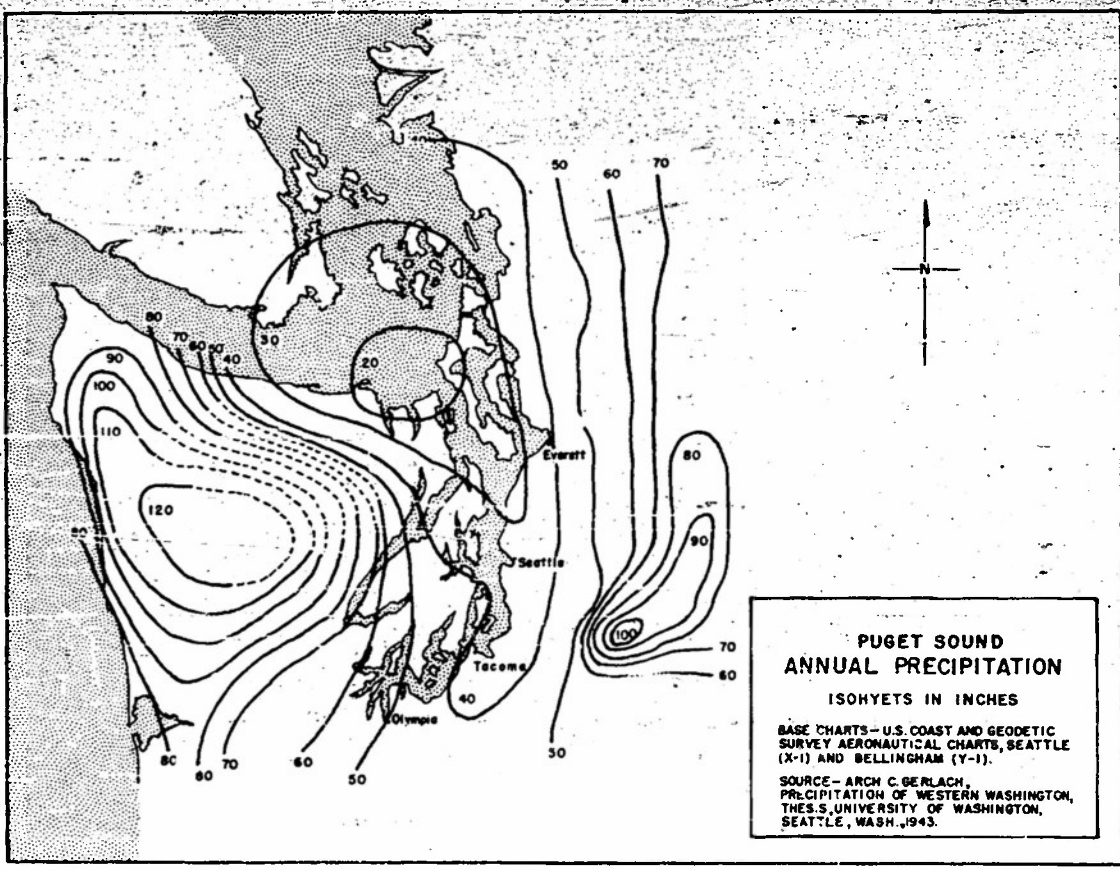
N
Everett
Seattle
Tacoma
Olympia
PUGET SOUND
ANNUAL PRECIPITATION
ISOHYETS IN INCHES
BASE CHARTS – U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE (X-1) AND BELLINGHAM (Y-1).
SOURCE – ARCH C. GERLACH, PRECIPITATION OF WESTERN WASHINGTON, THES.S, UNIVERSITY OF WASHINGTON, SEATTLE, WASH., 1943.

Fig. 2-6

TABLE 2-8. Average Temperature [In Degrees Fahrenheit].

LOCATION	Yrs. of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average	Mean Max.	Mean Min.	Highest Temp.	Lowest Temp.
Aberdeen	38	39.0	41.4	44.2	47.8	52.2	56.3	59.6	60.5	57.4	52.0	45.1	40.4	49.7	58.2	41.2	105	6
Anacortes	25	38.3	41.3	44.5	48.8	43.6	58.0	60.9	61.0	57.4	51.2	45.0	40.4	50.0	48.6	41.5	95	7
Bellingham	18	39.1	41.2	43.4	48.8	53.6	58.1	61.5	60.8	56.5	50.9	45.5	41.7	50.1	58.6	41.6	96	0
Blaine	31	35.6	38.7	42.1	47.4	52.7	57.8	61.2	60.4	55.2	48.8	43.0	38.0	48.4	57.6	39.2	95	-3
Bremerton	5	35.3	41.2	45.8	48.8	53.9	58.4	62.6	62.5	58.8	53.0	45.6	42.0	50.7	59.9	42.3	98	14
Coupeville	19	38.4	41.4	43.8	48.7	53.2	57.6	61.2	60.9	56.2	51.0	44.5	41.4	49.9	57.9	41.8	94	6
Everett	17	37.2	40.4	43.8	48.4	53.2	58.2	61.3	61.0	56.2	50.3	44.2	38.7	49.4	57.6	41.2	90	5
Grapeview	23	38.4	41.0	45.2	49.6	55.2	60.4	65.1	65.1	59.6	52.0	45.3	40.1	51.4	61.2	41.7	102	10
Keyport	10	39.0	42.2	45.2	49.8	55.0	60.0	63.7	63.3	59.2	52.6	45.6	41.1	51.4	60.3	42.5	98	11
Olga	39	38.9	42.1	44.0	48.3	53.0	57.0	59.7	54.6	56.2	50.2	44.6	44.0	49.4	56.3	42.6	89	-3
Olympia	51	38.3	40.6	44.6	49.0	54.8	59.5	63.3	63.4	57.8	51.2	44.8	40.7	50.7	60.3	41.0	104	-2
Port Angeles	30	37.3	39.0	41.8	45.5	50.3	54.5	57.1	57.8	53.9	48.2	42.6	39.1	47.3	54.2	39.8	92	-1
Port Townsend	37	39.2	41.4	44.0	48.4	53.0	57.2	60.4	60.6	57.2	51.2	45.4	42.0	50.0	56.8	43.1	90	-3
Quilcene	11	36.0	39.4	43.0	47.4	53.2	58.7	62.6	62.4	56.2	49.8	42.1	37.6	49.0	60.6	37.4	99	0
Seattle	40	39.8	41.9	45.0	49.6	54.8	59.6	63.8	63.7	58.8	52.3	46.0	41.8	51.4	58.1	44.7	98	3
Sedro Woolley	33	37.0	40.2	44.4	49.9	54.8	59.5	62.6	61.6	56.4	51.2	44.0	39.2	50.1	59.9	40.5	99	-1
Sequim	12	37.2	39.2	41.9	46.8	51.2	56.5	59.0	59.6	56.0	49.3	42.2	37.8	48.1	57.5	38.6	91	1
Tacoma	33	38.9	41.2	44.7	49.1	54.5	59.4	63.6	63.4	58.4	51.6	45.5	40.6	50.9	58.3	43.6	98	7
Tatoosh Island	42	41.2	42.1	43.9	46.7	50.1	53.2	55.3	55.5	54.0	51.0	46.7	44.0	48.7	52.3	44.9	88	7
Vancouver, B.C.	28	35.6	38.3	42.2	47.6	53.9	59.0	63.3	62.3	56.4	49.4	42.7	38.3	49.1	56.1	42.1	92	2
Vashon Island	32	39.3	41.2	44.2	48.6	53.7	58.6	62.8	62.4	57.7	51.2	44.8	40.6	50.4	58.4	42.5	94	5
Victoria, B.C.	43	38.6	40.4	43.6	48.4	53.0	57.0	59.9	59.9	56.0	50.4	44.6	41.0	49.4	55.9	42.9	95	-2

Table modified from Climatic Summary of the United States (U. S. Department of Agriculture Weather Bureau 1936), and The Canadian Climate (Koeppe 1931).

TABLE 2-9. Average Hourly Wind Velocities (Miles Per Hour). [True Velocities]

LOCATION	Yrs. of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average
Port Angeles	15	6.7	6.6	7.1	7.3	7.7	7.5	7.7	6.7	5.9	5.7	3.8	6.7	6.6
Seattle	20	9.8	9.0	9.8	9.1	9.0	8.4	7.8	7.3	7.8	8.3	9.2	9.7	8.8
Tacoma	8	7.9	8.3	8.3	8.6	8.4	8.3	7.7	7.2	7.3	7.4	7.1	8.1	7.9
Tatoosh Island	41	18.1	16.7	14.7	12.8	11.3	9.9	9.6	9.9	11.5	13.8	16.8	18.5	13.6
Vancouver, B.C.*	20	3.7	4.0	4.4	4.5	4.3	4.0	3.8	3.4	3.4	3.3	3.4	4.1	

Table modified from Climatic Summary of the United States (U. S. Department of Agriculture Weather Bureau 1936) and *Climatic Summaries (Canada Department of Transport Meteorological Division 1948).

TABLE 2-10. Maximum Wind Velocity and Direction (Miles Per Hour). [True Velocities]

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
Port Angeles	34 N	36 SW	37 W	31 SW	31 W	31 W	29 NW	33 W	30 SW	30 SW	38 NE	38 NE	38 NE
Seattle	46 S	45 S	43 SW	43 SW	35 SW	38 SW	38 W	34 S	38 S	46 SW	50 SW	53 SW	53 SW
Tacoma	35 SW	40 S	35 E	42 S	37 SW	35 SW	32 SW	26 W	32 S	34 S	35 S	43 SW	43 SW
Tatoosh Island	84 SW	68 NE	62 S	61 SW	56 S	54 S	47 SW	43 E	59 S	64 SW	71 S	69 SW	84 SW

Table modified from Climatic Summary of the United States (U. S. Department of Agriculture Weather Bureau 1936).

TABLE 2-11. Prevailing Wind Direction.

LOCATION	Yrs.of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average
Aberdeen	38	E	E	W	W	W	W	W	W	W	W	E	E	W
Bellingham	10	SE	SE	W	SW	SW	SW	SW	W	W	W	SE	SE	SW
Blaine	32	NE	NE	SW	W	SW	SW	SW	SW	SW	SW	NE	NE	SW
Coupeyille	28	SE	SE	SE	W	W	W	W	W	W	W	SE	SE	W
Cushman Dam	6	SW	SW	SW	SW	SW	SW	SE	SE	SE	SW	SW	SW	SW
Everett	16	SE	S	W	W	W	W	W	W	W	W	SE	SE	W
Grapeview	23	S	S	S	SW	S	S	S	S	S	S	S	S	S
Keyport	9	S	S	S	S	S	S	S	S	S	S	S	S	S
Olga	39	SE	SE	SE	SW	SW	SW	SE	SE	SE	SE	SE	SE	SE
Olympia	36	S	SW	SW	SW	SW	SW	NW	NW	N	SW	SW	S	SW
Port Angeles	30	S	S	S	S	W	W	W	W	S	S	S	S	S
Port Townsend	37	SE	SE	SE	W	NW	NW	W	NW	NW	NW	SE	SE	NW
Quilcene	11	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE
Seattle	38	SE	SE	S	S	S	S	N	N	S	SE	SE	SE	SE
Sequim	14	W	W	W	W	W	W	W	W	W	W	W	W	W
Tacoma	33	SW	SW	SW	SW	SW	N	N	N	N	SW	SW	SW	SW
Tatoosh Island	33	E	E	E	W	W	SW	S	S	S	E	E	E	E
Vashon Island	37	S	S	S	S	S	N	N	N	N	S	S	S	S

Table modified from Climatic Summary of the United States (U. S. Department of Agriculture Weather Bureau 1936).

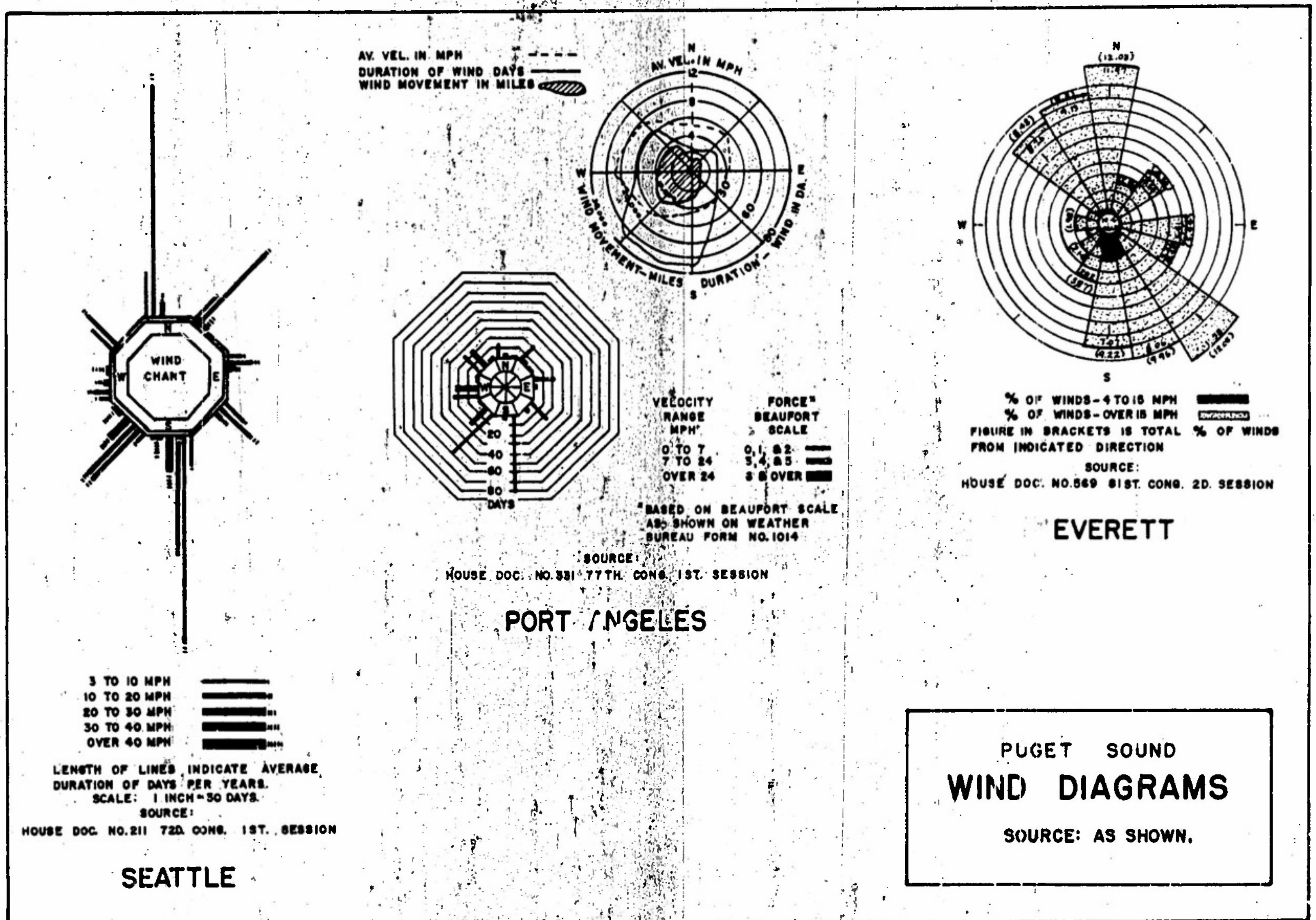
WIND CHART
3 TO 10 MPH
10 TO 20 MPH
20 TO 30 MPH
30 TO 40 MPH
OVER 40 MPH
LENGTH OF LINES INDICATE AVERAGE DURATION OF DAYS PER YEARS.
SCALE: 1 INCH = 50 DAYS.
SOURCE:
HOUSE DOC. NO.211 72D. CONG. 1ST. SESSION
SEATTLE
AV. VEL. IN MPH
DURATION OF WIND DAYS
WIND MOVEMENT IN MILES
AV. VEL. IN MPH
WIND MOVEMENT-MILES
DURATION-WIND IN DA.
VELOCITY RANGE MPH
0 TO 7
7 TO 24
OVER 24
FORCE* BEAUFORT SCALE
0, 1, & 2
3, 4, & 5
6 & OVER
*BASED ON BEAUFORT SCALE AS SHOWN ON WEATHER BUREAU FORM NO. 1014
DAYS
SOURCE:
HOUSE DOC. NO.331 77TH. CONG. 1ST. SESSION
PORT ANGELES
% OF WINDS - 4 TO 15 MPH
% OF WINDS - OVER 15 MPH
FIGURE IN BRACKETS IS TOTAL % OF WINDS FROM INDICATED DIRECTION
SOURCE:
HOUSE DOC. NO.569 81ST. CONG. 2D. SESSION
EVERETT
PUGET SOUND
WIND DIAGRAMS
SOURCE: AS SHOWN.

Fig. 2-7

That the prevailing winds are from a southerly quarter seems at variance with the statement that the prevailing air currents are from off the ocean. Local topography is largely responsible for this diversion of surface winds. More conclusive wind data is lacking because only three stations on Puget Sound are equipped with automatic recording wind instruments.

Chinook Wind

The Chinook is a warm wind which blows down the lee side of any mountain if there has been precipitation in the windward side. The Pacific Northwest is famous for this wind on the east slope of the Cascades in winter. Chinooks do occur on the west slope of the Cascades if rain or snow has fallen on the east slope of the Rockies during the rainy season (Church 1942). The local chinook is capable of melting an eight-inch snow cover in one day. This rapid melting of snow swells the streams producing floods whose turbulent muddy waters may be followed into Puget Sound.

STORMS

The Puget Sound Lowland is protected from intense storms. The paths of most of the severe storms as well as the paths of the traveling cyclones are usually oriented on the northwest-southeast axis nearly bisecting Puget Sound latitudinally.

Storms are most intense and frequent during winter because of the increased deepening of the Aleutian Low and the unobstructed path across the North Pacific. Winter storms are generally accompanied by high winds and heavier than average rainfall.

Snow Storms

The most notable snowstorms to occur in Seattle were: the storm of January 1834 (Fisher 1949); the "Big Winter" of 1861-62 where heavy rains were followed by disasterous floods and two feet of snow (Anonymous 1952); the winter of 1887 in which four and one-half feet of snow accumulated; and the winters of 1880, 1893, 1916, 1946, and 1950 (Fisher 1949).

Wind Storms

Two of the most notable wind storms caused considerable damage to Seattle and Tacoma. On October 21, 1934, the vessel PRESIDENT MADISON, tied up at Pier 41 [now Pier 91] in Seattle, was battered against the pier by the wind tearing up much of the pier. The ship broke loose and drifted in the slip, striking and sinking three small ships, one an ocean-going tug. Excessive vibration set up by wind caused the collapse of the Tacoma Narrows Bridge in the fall of 1940. There are no recorded velocities of this wind in the Tacoma Narrows but they were not excessive.

Thunderstorms

Thunderstorms are infrequent, averaging about five in a year, and some of these have only a few peals of thunder (U. S. Department of Commerce Weather Bureau 1948). Hailstones from these thunderstorms are quite rare and fall for only a minute or so and are usually quite harmless. The frequency and intensity of thunderstorms is insufficient to materially affect the amount of annual precipitation.

Lightning damage is infrequent in the lowland areas (Fisher 1945).

Tornadoes and hurricanes have not been observed in the Puget Sound area.

ATMOSPHERIC POLLUTION

Tacoma, Seattle and Everett all have an air pollution problem (Tyler 1948, 1952) which is aggravated by rapid industrial and residential expansion. Locally, smoke, flue gases, and dust increase the potential formation and continuation of fog and result in smog. Since Puget Sound is oriented on a north-south axis, as are its major cities, any wind from the north or south will readily spread the airborne pollutants over the entire area. Smog reduces visibility and insolation beyond that occasioned by fog alone. (See paragraph on Insolation, this section.) Illustrative of the amount of foreign matter carried in the atmosphere, the Harbor Patrol has attributed some of the apparent oil slicks on Lake Washington to deposits from dirt laden smogs (Tyler 1952).

Visibility

There is a definite relationship between haze or visibility and humidity. Combined smoke and humidity increase haze due to the hygroscopic action of smoke particles. Aerosols and sulfur dioxide (SO_2) are present in ordinary smoke and flue gases, of both industrial and residential origin. In the presence of sunlight, the sulfur dioxide is oxidized to sulfur trioxide (SO_3), a more hygroscopic compound. This reaction accounts for the rapid formation or increase in the amount of haze so noticeable just after sunrise in the Puget Sound region. For example, clear views of Mount Rainier are frequently observed from Tacoma and Seattle just prior to sunrise, while shortly thereafter haze may develop sufficiently to obscure the base or the entire mountain.

FOG

Fog in the Puget Sound Lowland is predominantly of the radiation type--forming first in the valleys on clear calm nights. The radiation fog may form very rapidly during the hours shortly after sunset, especially when clear skies and light wind velocities occur simultaneously. Other types of fog present within the region may be maritime, frontal, and prefrontal.

The maximum occurrence of fog is September to November. During late November and December the occurrence of fog drops rapidly due to increasing frequency of storms (Woodward 1941). The months of May to July have little fog. The number of days with dense fog decreases from south to north through the Puget Sound Lowland: Olympia averages 90 days per year with dense fog (visibility 0 to 1/4 mile), Tacoma 30 days, Seattle 24 days, Everett 17 days, and Bellingham 10 days (U. S. Department of Commerce Weather Bureau n.d.b). Rarely does fog continue all day; the sun generally dissipates the fog by noon. Tables 2-11 and 2-12 tabulate similar data. In and around Seattle the formation of fog appears to be considerably influenced by Lake Washington and Lake Sammamish as well as by Puget Sound. Fog formed over Lake Washington at night frequently moves landward after sunrise. During late summer and fall the relatively cold waters of Puget Sound may be blanketed in the morning with fog to the water's edge with little or none inland over the city. Conditions observed at most meteorological stations, generally located back from the water's edge, cannot be expected to correctly represent conditions over the water. Local variations within Seattle are evident from conditions reported for Sand Point (at the edge of Lake Washington) and Seattle (downtown near the Sound) as shown in Tables 2-12 and 2-13.

The average percentage of hours with dense fog, near large cities on Puget Sound, does not correspond to the average percentage of hours with low visibilities. Fog conditions are aggravated by pollutants discharged into the air from industrial and private chimneys. Consequently, the number of hours of low visibility will generally be greater than the number of hours of dense fog (Table 2-14).

INSOLATION

Information on the amount of insolation is limited to several locations within the city of Seattle, the Seattle-Tacoma Airport, and

TABLE 2-12. Average Occurrence of Dense Fog (Per cent of Hours).

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average
Bellingham	0.8	0.1	0.7	0.0	0.0	0.0	0.2	0.3	1.7	3.0	1.8	0.7	0.8
Everett	1.0	1.0	1.9	0.1	0.2	0.1	1.0	2.0	3.5	4.5	4.1	1.7	1.7
Sand Point	0.6	1.0	2.0	0.4	0.0	0.0	0.0	0.0	2.2	3.2	4.4	1.3	1.3
Seattle	3.5	3.0	1.0	0.3	*	0.1	*	0.4	3.3	9.0	7.4	4.6	2.7
Tatoosh Island	0.6	0.3	0.1	1.4	1.4	3.8	8.4	16.0	9.6	3.4	0.9	0.0	3.8

*Less than 0.05%

Table modified from the Pacific Coast Pilot (U. S. Department of Commerce Coast and Geodetic Survey 1951).

TABLE 2-13. Average Occurrence of Low Visibilities (Percent of Hours).

LOCATION	Yrs. of Record	Elevation in ft.	Miles Visibility	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average
Bellingham	2	103	0-¼	0.9	0.2	0.8	0.0	0.0	0.0	0.3	0.2	1.8	3.1	1.9	0.6	0.9
			0-½	1.7	0.5	1.4	0.0	0.0	0.0	0.4	0.5	2.4	4.7	2.5	1.0	1.3
			0-2	3.4	3.5	3.1	0.7	*	*	0.5	3.1	8.2	10.7	6.1	3.0	3.5
Everett	2	127	0-¼	1.0	1.1	2.2	0.1	0.2	0.1	1.1	2.0	3.3	4.5	4.1	1.8	1.8
			0-½	2.1	1.3	2.5	0.2	0.2	0.3	1.3	2.3	4.2	5.4	4.9	2.3	2.3
			0-2	6.1	3.6	4.5	1.7	0.7	2.2	2.7	6.2	13.5	12.6	10.6	5.7	6.0
Sand Point	2	540	0-¼	0.6	1.0	1.9	0.4	0.0	0.0	0.0	0.1	2.1	3.2	4.4	1.2	1.3
			0-½	0.8	1.2	2.1	0.7	0.0	0.0	0.2	0.2	4.0	4.7	5.0	1.6	1.8
			0-2	4.3	5.5	4.2	2.4	0.2	0.4	2.0	3.7	10.5	10.5	12.2	4.8	5.2
Seattle	8	30	0-¼	4.2	3.4	1.2	0.5	0.1	0.1	*	0.7	4.0	10.6	8.9	5.5	3.3
			0-½	5.5	4.4	1.5	0.6	0.1	0.2	0.1	1.2	5.7	12.6	11.1	7.4	4.2
			0-2	18.1	14.3	4.6	2.7	1.0	1.2	1.9	8.1	18.6	29.2	25.1	18.4	11.9
Tatoosh Island	4	86	0-¼	0.2	0.0	1.5	0.5	1.1	3.0	9.9	17.7	11.8	4.0	*	1.2	4.3
			0-½	0.4	0.1	1.7	0.9	1.6	3.4	11.6	20.5	13.3	4.8	*	1.6	5.1
			0-2	1.9	0.9	3.1	1.5	2.7	6.2	16.6	25.5	20.6	9.2	1.8	5.3	8.0

*Indicates less than 0.05%

Table modified from the Pacific Coast Pilot (U. S. Department of Commerce Coast and Geodetic Survey 1951).

TABLE 2-14. Average Hours of Operation of Fog Signals.

LOCATION	Yrs. of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Yearly Average
Alki Point	8	54	25	6	4	9	7	15	22	59	74	45	39	359
Brown Point	8	130	41	18	8	13	10	11	20	78	133	99	118	679
Burrows Island	7	28	9	5	6	17	23	46	60	79	23	16	10	322
Bush Point	8	29	16	4	5	16	13	42	53	76	62	28	21	365
Cresote Wharf	8	16	11	1	1	2	2	4	7	24	27	20	18	133
Dofflemeyer Point	8	47	32	15	9	6	4	3	7	31	64	43	55	316
Duwamish Head	7	101	32	11	5	9	6	12	11	45	110	115	81	538
East Waterway	8	33	15	2	1	2	1	1	5	31	69	44	54	258
Four Mile Rock	8	20	12	3	1	4	4	6	11	30	33	30	19	173
Johnson Point	5	13	13	12	6	5	3	5	8	25	42	20	13	165
Marrowstone Point	8	27	21	4	8	27	28	52	82	115	63	38	24	489
Milwaukee Shoal	8	58	27	8	3	4	1	1	2	36	83	64	76	363
Mukilteo Light	8	54	23	11	3	5	5	6	12	59	77	53	41	349
Olympia Shoal	8	34	21	9	5	3	3	2	5	21	41	44	43	231
Orchard Point	8	29	18	4	6	5	3	5	10	33	37	28	22	200
Partridge Point	8	68	28	19	25	41	42	85	144	223	135	73	57	940
Point Defiance	8	33	54	11	5	7	6	5	10	24	73	42	51	321
Point Glover	8	25	17	8	4	4	5	4	10	28	36	35	23	199
Point Herron	7	31	9	10	4	5	4	1	5	13	39	37	32	190
Point Monroe	4	19	12	5	4	8	6	11	21	39	25	35	12	197
Point No Point	8	129	64	35	25	36	23	56	84	151	172	116	96	987
Point Wilson	8	32	25	7	11	29	30	56	91	131	89	45	24	570
Pulley Point	2	15	3	13	0	2	7	14	9	44	64	91	10	272
Robinson Point	8	71	28	13	9	10	9	11	25	72	99	69	53	469
Tacoma Waterway	8	43	28	14	3	5	4	4	6	28	70	76	94	375
Waterman Point	8	23	11	6	4	3	4	1	8	19	37	37	22	175
West Point	8	52	27	9	5	8	5	16	22	50	67	44	60	365
West Waterway	8	37	12	4	1	1	1	T	4	28	56	48	43	235

T = Trace

Table compiled from original data on file in the office of the 13th Coast Guard District, Seattle (U. S. Treasury Department Coast Guard 1952).

Friday Harbor on San Juan Island. The pyroheliometers at these locations show that the average insolation for the Seattle area is 190 gram-calories per square centimeter per day during winter and 520 g-cal/cm^2/day during summer. Friday Harbor has about the same amount of insolation in summer as Seattle but has approximately 40 g-cal/cm^2/day less than Seattle during winter (Crabb 1950; Tyler 1952; Glaser 1941; Phifer and Utterback 1935).

SUNSHINE AND CLOUDINESS

The average amount of sunshine is 40 to 45 per cent of the total possible over the Puget Sound Lowland. Summer is the sunny season with Seattle reporting an average of 60 to 64 per cent. During the winter sunshine averages slightly above 20 per cent (Church 1942). The number of hours of sunlight as reported by the Weather Bureau for Seattle for 1950 was only 1836, or an average of 4.56 hours per day, which is 38 per cent of the possible (Tyler 1952). Few Weather Bureau stations have recorded sunshine and cloudiness in the Puget Sound area.

FROST-FREE SEASON

The average length of the frost-free season for all stations on the shores of Puget Sound is 207 days. In the valleys' tributary to Puget Sound it drops to 167 days, and nearer to the mountains it is shorter (U. S. Department of Agriculture Weather Bureau 1936). See Fig. 2-8.

SURFACE ICE AND ICING CONDITIONS

Ice has never been a problem to navigation in Puget Sound although for brief periods during the colder winters a few inches have formed locally. This has occurred at the heads of long quiet inlets such as Carr Inlet, Hood Canal, and Liberty Bay which tend to retain a surface layer of low salinity water not readily intermixed with that at depth. Ice usually forms first in Liberty Bay which is relatively shallow, wherein much of its upper reaches baring at low tide, and mixing with outside waters is restricted. During the severe winter of 1949-1950 most of the small inlets were frozen over and ice covered Hood Canal from Lilliwaup to its head in Lynch Cove, a distance of about 18 miles. This ice overlay water which in the upper 60 feet increased in salinity from 23 ‰ to 29 ‰, in density expressed as sigma-t from 21 to 23, and in temperature from the freezing point to 48° F. Unpublished data on file for 1 February 1950 (University of Washington Department of Oceanography n.d.). The great stability of the near surface water prevents convective turnover such as is normally associated with prolonged

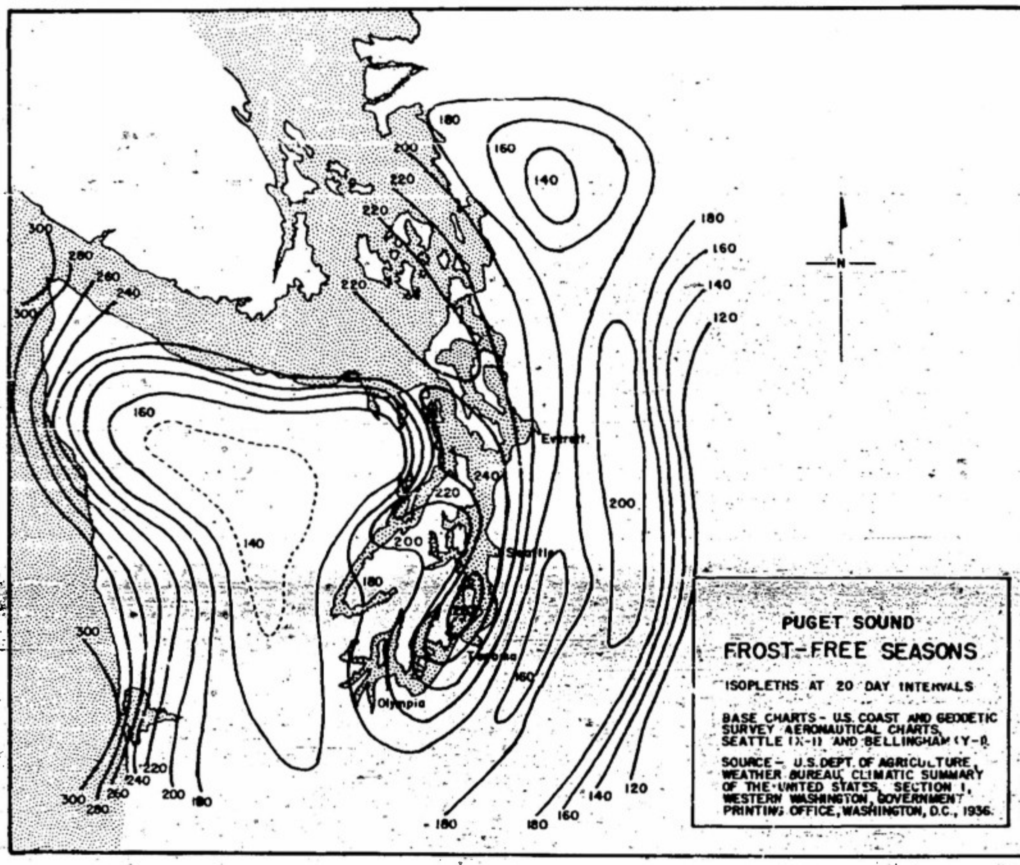
PUGET SOUND
FROST-FREE SEASONS
ISOPLETHS AT 20 DAY INTERVALS
BASE CHARTS - U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE (X-1) AND BELLINGHAM (Y-1)
SOURCE - U.S. DEPT. OF AGRICULTURE, WEATHER BUREAU, CLIMATIC SUMMARY OF THE UNITED STATES, SECTION 1, WESTERN WASHINGTON, GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C., 1936.
Everett
Seattle
Tacoma
Olympia
N
300
280
260
240
220
200
180
160
140
120

Fig. 2-8

and intense cooling in higher latitudes, the loss of heat being largely limited to a surface layer a few meters thick, with cooling inappreciable throughout most of the water column. At the entrances to the bays and inlets where currents cause vertical mixing, temperatures several degrees above freezing always persist to the very surface and no ice forms.

Ice on the fresh water bodies near Puget Sound is a more frequent occurrence. During the severe winter of 1861-62 ice six inches deep covered Lake Union and Union Bay, while the main part of Lake Washington was not frozen. At this time Lake Union remained frozen for six weeks (Anonymous 1952).

SPECIAL PHENOMENA

Certain physical and meteorological effects are commonly observed on Puget Sound. Others are experienced only by those who spend the greater part of their lives on the local waters. No known research has been carried out within the fields of these phenomena on Puget Sound nor has any literature been developed. A few of the more commonly observed phenomena are cited below.

Optical Phenomena

Optical illusions in which ships and land masses appear distorted or unusual in aspect or position are commonly observed in the Puget Sound area, particularly in the approaches at the head of the Strait of Juan de Fuca. Vertical distortion predominates giving a flattened or, as is more frequently noticed, a towering appearance to ships, bluffs, and headlands. There have been reports of ships looming above the horizon in an inverted position. Towering is noticed most frequently on summer afternoons of sunny days when winds are not in excess of a few knots. At such times a gentle flow of warm dry air from land over the relatively cold water at the head of the Strait favors a pronounced near surface inversion of air temperatures which first increases with height above the water and then decreases giving an air layer characterized by abnormal refraction. The magnitude of the distortion frequently changes appreciably with small changes in the height of the observer's eye above water. Objects appearing strongly distorted at an eye position near the water line may appear normal from bridge or upper deck levels.

Within Puget Sound proper the differential temperature (air temperature minus sea temperature) is usually less than in the Strait, and the over water distances of sight are relatively short minimizing abnormal refraction and making that which occurs less apparent. Lateral temperature gradients and resulting lateral refraction likely occur in the vicinity of bluffs and headlands but reports are inconclusive.

Unusual refraction can lead to serious errors in the use of range finders and stadimeters. On the other hand ships which appear distorted are usually identifiable as to type and sometimes as to name.

Local Radio Phenomena

There are several radio dead spots on Puget Sound. One such area is Fauntleroy Cove on the east side of Puget Sound just across from the northern tip of Vashon Island. Ship to shore radio is frequently not possible, especially in attempts to contact Seattle. Between McNeil and Anderson Islands radio reception is frequently badly garbled.

The best radio reception seems to occur in the San Juan Islands, just north of Puget Sound proper. It is not at all uncommon to receive Canadian, eastern, gulf state, and Mexican stations on the regular broadcast band in the San Juan Islands. However, certain areas directly behind the larger islands in the San Juan group render Seattle broadcasts difficult to receive while allowing those from California clear reception.

Accoustical Phenomena

Several accoustical dead spots exist in areas adjacent to fog signals. Most notable of these is an area about one mile north of Point Wilson and an area about one and one-half miles southwest of Burrows Island. A ship may pass in and out of a zone of silence bearing toward the land and will not encounter such a zone nearer to the shore. These dead spots occur during all seasons but only during periods of calm or very light wind.

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1947. Normal Annual Isohyetal Map. Map File No. D-11-13-16.1, Seattle District, Seattle, Washington. (Covering Olympic and Cascade drainage basins, Washington.)

1950. Everett Harbor and Snohomish River, Washington. House Document No. 569, 81st Congress, 2d Session, 31 pages, 2 maps. (Contains a review of reports of Everett Harbor and Snohomish River with two detailed charts of the docks in the harbor and river installations. Wind.)

U. S. Department of Agriculture
1936. Atlas of American Agriculture. Government Printing Office, Washington, D.C.
(Physical basis including land relief, climate, soils, and natural vegetation of the United States. Section on climate is comprehensive.)

1941. Climate and Man, Yearbook of Agriculture. House Document No. 27, 77th Congress, 1st Session, Government Printing Office, Washington, D.C.
(Offers a complete climatic summary for the entire state by counties and cities.)

U. S. Department of Agriculture Weather Bureau
1906. Climatology of the United States. Washington, pp. 925-945, Bulletin Q, W.B. no. 361, Government Printing Office, Washington.
(General and specific data given for stations by Puget Sound.)

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(A comprehensive discussion and analysis of climatic conditions; precipitation; snowfall; temperature, winds, humidity, frosts.)

U. S. Department of Commerce Coast and Geodetic Survey
1951. United States Coast Pilot, Pacific Coast, California, Oregon, and Washington, Seventh (1951) Edition. Serial no. 750. Government Printing Office, Washington, D.C., 578 pages.
(Complete description of the Puget Sound region, including all bodies of water, harbors, points, etc.)

U. S. Department of Commerce Weather Bureau
n.d.a. Climatological Station Records. (Unpublished.)
(Additional information on hand at all First-order stations.)

n.d.b. Records of Surface Observations. (Unpublished.)
(Records on forms WB-1001B or 1130. Also included in these records are the Bellingham and Everett CAA Offices and the Whidbey Island NAS Office.)

n.d.c. Hydrologic Bulletin, Hourly and Daily Precipitation, North Pacific District, January 1947. Published monthly in cooperation with U. S. Army Corps of Engineers, Government Printing Office.
(Precipitation for all stations in Washington.)

U. S. Department of Commerce Weather Bureau

1941. Daily Weather Maps. Seattle Aerological Station, Seattle, Washington.
(Published daily from 1931 through December 1941. Discontinued at start of war.)

1942. Daily Weather Bulletin. Seattle Aerological Station, Seattle, Washington.
(Discontinued after one week from commencement in January due to the war.)

1947. Maximum Recorded United States Point Rainfall for 5 minutes to 24 hours at 207 First-Order Stations. Weather Bureau Technical Paper no. 2, 36 pages, Government Printing Office, Washington, D.C.
(Puget Sound area included.)

1948a. Annual Meteorological Summary with Comparative Data 1947, Seattle, Washington. Portland, Oregon: Weather Bureau Office, 16 pages.
(Tables of wind, temperature, precipitation, sunshine, snowfall, and a short history of the climate of Seattle.)

1948b. Highest Persisting Dewpoints in Western United States. Weather Bureau Technical Paper no. 5, 27 pages, Government Printing Office, Washington, D.C.
(Puget Sound area included.)

1949a. Mean Precipitable Water in the United States. Weather Bureau Technical Paper no. 10, 48 pages, Government Printing Office, Washington, D.C.
(Data for Seattle included.)

1949b. Temperatures at Selected Stations in the United States, Alaska, Hawaii, and Puerto Rico. Weather Bureau Technical Paper no. 9, 20 pages, Government Printing Office, Washington, D.C.
(Seattle, Tacoma, and Tatoosh Island included.)

1949c. Weekly Mean Values of Daily Total Solar and Sky Radiation. Weather Bureau Technical Paper no. 11, 17 pages, Government Printing Office, Washington, D.C.
(Data for Friday Harbor included.)

1950a. Local Climatological Summary with Comparative Data, 1949, Port Angeles. Government Printing Office.

1950b. Local Climatological Summary with Comparative Data, 1949, Seattle. Government Printing Office.

U. S. Department of Commerce Weather Bureau
1950c. Mean Monthly and Annual Evaporation, from Free Water Surface for the United States, Alaska, Hawaii and West Indies. Weather Bureau Technical Paper no. 13, 10 pages. Government Printing Office, Washington, D.C.
(Data for Seattle included.)

1951. Sunshine and Cloudiness at Selected Stations in the United States, Alaska, Hawaii, and Puerto Rico. Weather Bureau Technical Paper no. 12, 16 pages. Government Printing Office, Washington, D.C.
(Seattle, Tacoma, and Tatoosh Island included.)

1952a. Local Climatological Summary with Comparative Data, 1951, Olympia. Government Printing Office.
(Offers the only comprehensive data for the station.)

1952b. Local Climatological Summary with Comparative Data, 1951, Tacoma. Government Printing Office.
(Offers the only comprehensive data for the station.)

1952c. Local Climatological Summary with Comparative Data, 1951, Tatoosh Island. Government Printing Office.
(Offers the only comprehensive data for the station.)

1952d. Climatological Data - National Summary. Government Printing Office; nos. 1-12, monthly; no. 13, annual; vol. 3, 1952.
(Contains summary data for Washington and the Puget Sound area.)

1952e. Climatological Data - Washington. Government Printing Office; nos. 1-12, monthly; no. 13, Annual Summary; vol. LVI, 1952.
(This is the complete report for the state.)

1952f. Local Climatological Data, Seattle, Washington, November 1952. Government Printing Office.
(Issued monthly--the basic station report.)

1952g. Maximum 24-hour Precipitation in the United States. Weather Bureau Technical Paper no. 16, 284 pages, Government Printing Office, Washington, D.C.
(Puget Sound area included.)

1952h. United States Meteorological Yearbook 1943-1949. Government Printing Office, Washington, D.C., 137 pages.
(Data similar to that in National Climatological Summary.)

U. S. Treasury Department Coast Guard
1952. Hours of Fog Summary for the years 1942-1945, 1947-1949, 1951-1952. From the official record of the 13th Coast Guard District, Seattle, Washington. (Unpublished.)

Woodward, Wendell H.
1941. Fog and Stratus at Seattle. Bulletin of the American Meteorological Society, vol. 22, no. 6, pp. 242-249. (A four-year survey (1936-39) of all low ceiling and fog conditions at Seattle. Fog analysis--types, occurrence with prevailing wind, time of formation, duration.)

Yarnell, David L.
1935. Rainfall Intensity - Frequency Data. U. S. Department of Agriculture, Miscellaneous Publication no. 204, Washington, D.C., 67 pages. (Consists of methods of investigation, tables and maps of data, and explanation for use. Puget Sound area included.)

SECTION 3: HYDROLOGY

1 June 1953

HYDROLOGY

SURFACE WATER

INTRODUCTION

Few marine embayments in the United States may surpass Puget Sound in variability of fresh water influx from surface and subterranean streams. The topographic configuration, altitude, and climatic variation present in the area is of prime importance. Other environmental conditions govern the regimen of the principal rivers as they flow from elevations divisible into four of the six life zones as devised by C. Hart Marriam. While arbitrary, these zones are of value in comparing sections of the basins which are totally different in geographic character. Heavy timber and other vegetation may be found through the Transition Zone (elevation up to 3,000 feet), the Canadian Zone (3,000 to 5,000 feet), and the Hudsonian Zone (5,000 to 6,500 feet). The Arctic-Alpine Zone (above 6,500 feet) lies above the forest line with barren rocky soils, perpetual snow fields and glacial ice.

Little conclusive information is available concerning the overall water yield and runoff pattern because continuous records are not available for all streams entering Puget Sound nor are gaging stations located close to the mouths of the rivers. Due to the complex climatic and geologic nature of the individual river basins within the Puget Basin, the total water yield from surface and subterranean streams may not be adequately approximated.

RELATIONSHIP OF RIVERS TO BASIN TOPOGRAPHY

Figure 3-1 outlines the complete drainage pattern for the Puget Basin and delineates the boundaries for each local drainage area. The area of land encompassed in each local drainage area readily shows the importance of understanding the history of the water as it flows from the mountains to the Sound. Table 3-1 shows the area of each individual drainage basin together with comparative areas of gaged and ungaged portions of each basin. Figure 3-2 shows diagrammatically the same data. Figure 3-3 shows area between sea level and 1,000 feet, 1,000 and 6,500 feet, and 6,500 feet and up. Over 100 square miles of glacier area is also shown. The area below 1,000 feet, half of which is ungaged, shows the need to recognize the fact that river discharge records do not adequately represent the total surface runoff for the basin. The extent of glaciers in some individual drainage areas (3.6 per cent for the Puyallup Basin) is significant in terms of the two peak periods of river flow and sediment accumulation.

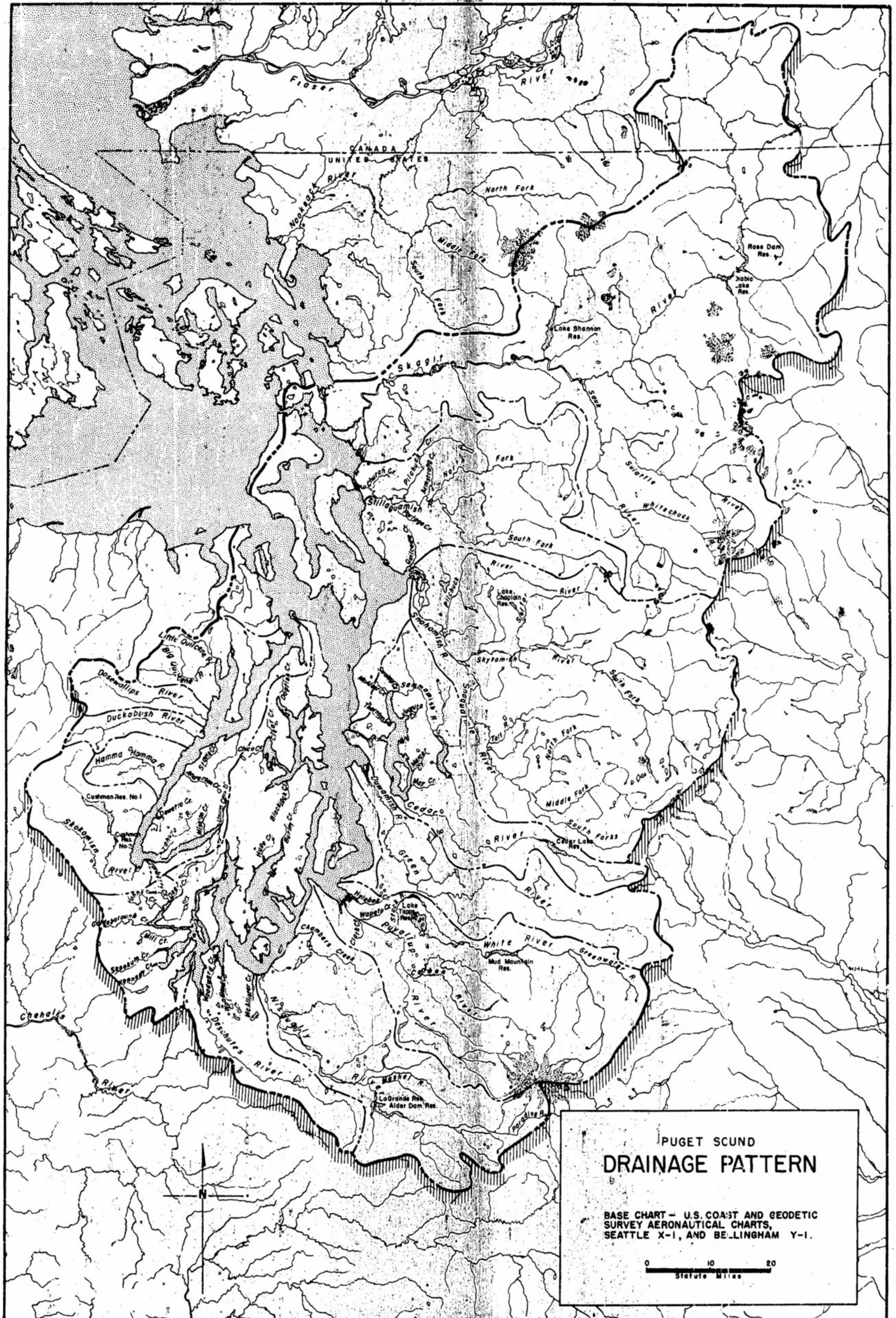

PUGET SOUND
DRAINAGE PATTERN
BASE CHART – U.S. COAST AND GEODETIC SURVEY AERONAUTICAL CHARTS, SEATTLE X-1, AND BELLINGHAM Y-1.
0 10 20
Statute Miles
CANADA
UNITED STATES
Fraser River
Nooksack River
North Fork
Middle Fork
South Fork
Skagit
River
Ross Dam Res.
Diablo Lake Res.
Lake Shannon Res.
Sauk
Suiattle
Whitechuck
Stillaguamish
South Fork
Lake Chaplain Res.
Snohomish R.
Skykomish River
Sammamish
Tolt R.
Snoqualmie River
Cedar
Cedar Lake Res.
Green
River
White River
Greenwater R.
Mud Mountain Res.
Puyallup
Lake Tapps Res.
Carbon
Chambers Creek
Nisqually
Mashel R.
LaGrande Res.
Alder Dam Res.
Paradise R.
Deschutes River
Chehalis
River
Skokomish
River
Cushman Res. No. 1
Hamma Hamma R.
Duckabush River
Dosewallips River
Little Quilcene R.
Big Quilcene R.
N

Fig. 3-1

TABLE 3-1. Drainage Areas in the Puget Sound Basin.* [In square miles]

DRAINAGE BASIN OR AREA	DRAINAGE AREA	GAGED AREA	UNGAGED AREA	% OF AREA GAGED	AREA OF ELEVATION			GLACIER AREA
					0-1,000'	1,000'-6500'	Above 6500'	
Skagit	3,191	3,092	99	97	402	2,640	149.0	64.0
Stillaguamish	776	635	141	82	330	445	0.6	1.2
Snohomish	1,734	1,695	39	98	622	1,111	1.0	3.0
Lake Washington	546	471	75	86	410	136	0	0
Duwamish	488	395	93	81	214	274	0	0
Puyallup	1,009	954	55	95	298	684	26.1	37.9
Nisqually	821	639	182	78	434	382	5.4	6.0
Deschutes	263	239	24	91	204	59	0	0
Shelton	219	85	134	39	199	20	0	0
Great Peninsula into Puget Sound proper	415	83	332	20	411	4	0	0
Great Peninsula into Hood Canal	230	57	173	25	229	1	0	0
Skokomish	286	247	39	86	106	180	0	T
Hamma Hamma	102	81	21	79	18	83	0.6	0
Duckabush	86	66	20	79	14	72	0.5	T
Dosewallips	126	120	6	95	12	113	1.2	0.6
Quilcene	101	85	16	84	31	70	0.6	T
Island & other areas	684	0	684	0	684	0	0	0
Puget Sound (total)	11,077	8,944	2,133	81	4,618	6,274	184.0	112.7

*Original data, planimetered from U. S. Coast and Geodetic Survey Aeronautical Charts - Seattle X-1 and Bellingham Y-1.

T - Area less than 0.6 square miles.

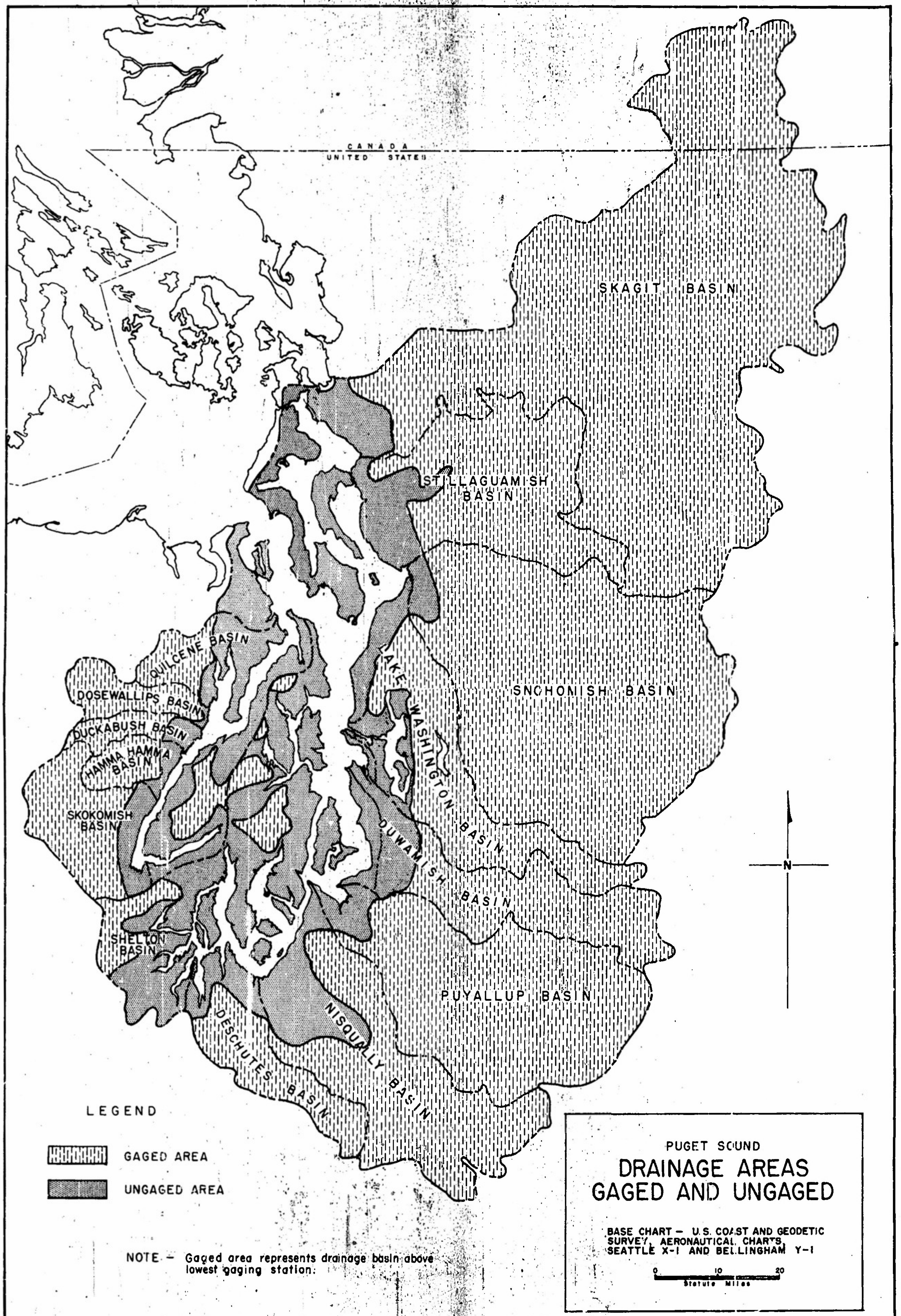
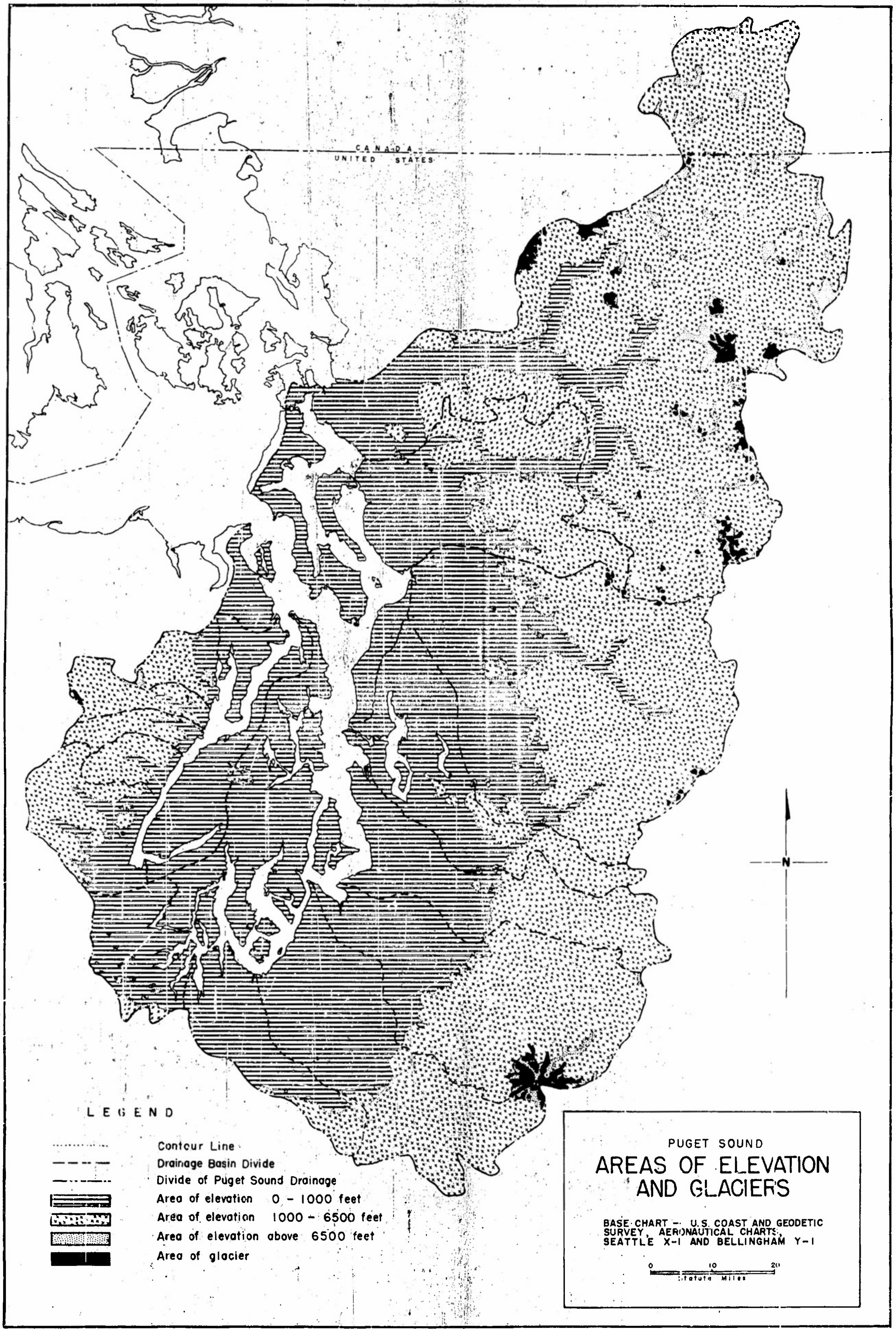

CANADA
UNITED STATES
SKAGIT BASIN
STILLAGUAMISH BASIN
SNOHOMISH BASIN
LAKE WASHINGTON BASIN
DUWAMISH BASIN
PUYALLUP BASIN
NISQUALLY BASIN
DESCHUTES BASIN
SHELTON BASIN
SKOKOMISH BASIN
HAMMA HAMMA BASIN
DUCKABUSH BASIN
DOSEWALLIPS BASIN
QUILCENE BASIN
N
LEGEND
GAGED AREA
UNGAGED AREA
NOTE – Gaged area represents drainage basin above lowest gaging station.
PUGET SOUND
DRAINAGE AREAS
GAGED AND UNGAGED
BASE CHART – U.S. COAST AND GEODETIC SURVEY, AERONAUTICAL CHARTS, SEATTLE X-1 AND BELLINGHAM Y-1
0 10 20
Statute Miles

Fig. 3-2



CANADA
UNITED STATES
N
LEGEND
Contour Line
Drainage Basin Divide
Divide of Puget Sound Drainage
Area of elevation 0 - 1000 feet
Area of elevation 1000 - 6500 feet
Area of elevation above 6500 feet
Area of glacier
PUGET SOUND
AREAS OF ELEVATION AND GLACIERS
BASE CHART - U.S. COAST AND GEODETIC SURVEY, AERONAUTICAL CHARTS, SEATTLE X-I AND BELLINGHAM Y-I
0 10 20
Statute Miles

Fig. 3-3

Precipitation

The general precipitation pattern for the Puget Lowland has been described in the section on Climatology. Emphasis must be placed here, however, upon the specific variability problems encountered with snow as one passes from sea level at Puget Sound through the lowland valleys and into the mountains.

SNOWFALL. Generally the annual snowfall for the Puget Lowland is small and no significant amount is likely to accumulate along the shore of the Sound. The total average duration of snow cover over most of the Puget Lowland is less than five weeks. The area with the shortest duration is the Skagit Flat lying between Everett and Bellingham (Church 1940b). See Table 3-2.

In the higher elevations of the Puget Basin, snow of great depth is known to accumulate. The average depth of snow of 184 inches (15.3 feet) at Paradise Inn (5,550 feet) on the flank of Mount Rainier is regarded as probably the point of greatest snowfall in North America (Meinzer 1942). Other areas may be compared to Paradise Inn in Table 3-2. Total snowfall at precipitation stations above 1,000 feet elevation is shown in Table 3-3.

RUNOFF CHARACTERISTICS

In general, streams flowing into Puget Sound may be divided into two principal types based upon the occurrence of peak runoff periods. Streams rising to relatively low elevations, being wholly rain fed, show one period of peak runoff. Streams rising to higher elevations show two periods of peak runoff due to both rain and melt water from snow fields and glaciers.

Two Peak Runoff

Streams rising in the mountainous areas of the Puget Basin are characterized by two high-water periods each year: the first period, October through March, is referred to as the winter high-water period; and the second, April through June, is referred to as the spring high-water period. The hydrograph of the Skagit River, which is this type, is shown in Fig. 3-4.

Winter peaks occur during the period when precipitation is heavy. They are usually caused by warm southwest storms with rainfall making up the bulk of the flood water--sometimes augmented by snow melt, especially if the snow mantle extends to a low elevation at the beginning of the storm. These floods are characterized by peaks of relatively high magnitude and short duration. Almost without exception, the destructive floods in this region are floods of this type.

TABLE 3-2. Average Depth of Snow on Ground on 15th and 31st of the Month.

LOCATION	Elevation in feet	Yrs. of Record	October		November		December		January		February		March		April	
			15	31	15	30	15	31	15	31	15	28	15	31	15	30
Aberdeen	105	21	0	0	0	0	0.3	0	0	1	0.7	0	0	0	0	0
Anacortes	60	21	0	0	0	0	0.2	0	0.1	0.3	0.1	0	0	0	0	0
Bellingham	107	22	0	0	0	0	0.8	0	0.5	1.3	0.2	0	0	0	0	0
Blaine	57	22	0	0	0	0	0.7	0	0.3	0.1	0.5	0	0	0	0	0
Bremerton	7	20	0	0	0	0	0.1	0.1	0.1	1.7	-	-	-	-	-	-
Coupeville	30	19	0	0	0	0	0.3	0	0.2	0.5	0.05	0	0	0	0	0
Everett	127	21	0	0	0	0	0.5	0	0.1	0.9	0.4	0	0	0	0	0
Grapeview	30	19	0	0	0	0	0.15	0	0.1	0.8	0.5	0	0	0	0	0
Keyport	46	17	0	0	0	0	0.38	0.3	0.16	1.4	0.4	0	T	T	0	0
Mt. Baker*	4200	11	0.7	4	27	32	52	95	108	121	125	141	148	175	172	141
Olga	60	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Olympia	69	24	0	0	0	0	0.5	0.2	0.5	1.5	0.2	0	0	0	0	0
Paradise Inn*	5550	17	3	8	20.5	36	65	87	116	136	144	157	166	184	181	163
Port Angeles	29	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port Townsend	80	23	0	0	0	0	0.3	0	T	0.8	0	0	0	0	0	0
Quilcene	30	17	0	0	0	0	T	0	T	0.5	0.2	0	0	0	0	0
Seattle	160	20	0	0	0	0	0.7	0	T	0.5	0.5	0	0	0	0	0
Sedro Woolley	48	20	0	0	0	0	0.3	0	0	0.8	T	0	0	0	0	0
Sequim	187	20	0	0	0	0	0.3	T	0.3	0.4	0	0	0	0	0	0
Tacoma	194	17	0	0	0	0.2	0.2	0.3	0.2	1.1	0.6	0.1	0	0.09	0	0

T = Trace

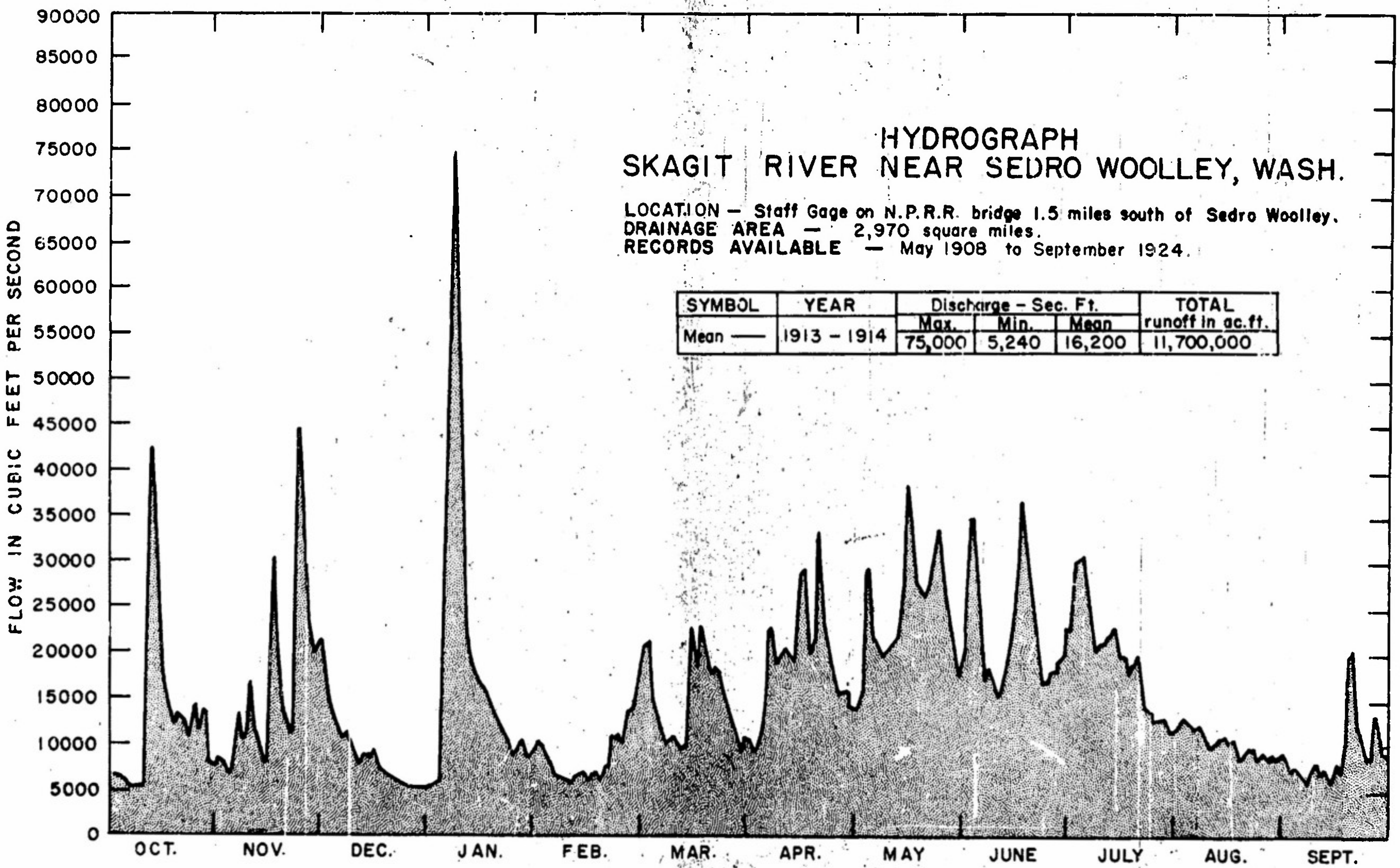
*Example of snow accumulation in the mountains of the Puget Sound Basin.

Table modified from Type Curves and Variability of Annual Snowfall (Church 1941c).

TABLE 3-3. Annual Snowfall at Precipitation Stations Above 1,000 feet in the Puget Sound Basin.

STATION	YEARS OF RECORD	ALTITUDE [Feet]	SNOWFALL [Inches]
Ashford	12	1,775	64 8
Cedar Lake	24	1,560	84.3
Fairfax	4	1,310	20.1
Goat Lake	9	2,900	261.1
Lester	12	1,626	83.0
Longmire	19	2,761	184.4
Monte Cristo	4	2,872	442.4
Mount Baker Lodge	4	4,200	477.5
Paradise Inn	11	5,550	591.3
Silverton	11	1,511	87.8
Snoqualmie Pass	17	3,010	398.0
Stampede Pass	11	2,856	205.7
Tye	11	3,126	365.8

Table modified from U. S. Department of Agriculture Weather Bureau 1936.



HYDROGRAPH
SKAGIT RIVER NEAR SEDRO WOOLLEY, WASH.
LOCATION — Staff Gage on N.P.R.R. bridge 1.5 miles south of Sedro Woolley.
DRAINAGE AREA — 2,970 square miles.
RECORDS AVAILABLE — May 1908 to September 1924.
SYMBOL | YEAR | Discharge - Sec. Ft. Max. | Min. | Mean | TOTAL runoff in ac.ft.
Mean —— | 1913 - 1914 | 75,000 | 5,240 | 16,200 | 11,700,000
FLOW IN CUBIC FEET PER SECOND
90000
85000
80000
75000
70000
65000
60000
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.

Fig. 3-4

Spring peaks occur when the warmer temperatures begin melting the accumulated snow pack of the higher altitudes. Flood waters are largely snow melt, sometimes augmented by spring rains. It may be seen that the hydrograph of this period is characterized by a rounded peak of long duration (Bodhaine and Robinson 1952).

Single Peak Runoff

Streams rising at lower altitudes have only one high-water period, October through March. The peaks of these streams are similar in cause and characteristics to the winter peaks described above. Little or no winter accumulation of snow is present in the spring to cause an appreciable spring high-water period. However, some temporary storage in the form of snow sometimes adds to the magnitude of the winter peaks (Bodhaine and Robinson 1952). A hydrograph of the Deschutes River is shown in Fig. 3-5.

During the periods of lowest flows, high tides reverse the flow in some rivers near their mouths.

ESTIMATION OF RUNOFF

Attempts to estimate stream discharge from precipitation records are usually futile in the Puget Basin because of the few and scattered precipitation stations being maintained. These stations are located in the valleys or river canyons in situations which do not afford records representative of large areas. Also, practically no records of precipitation have been kept in the higher elevations of the drainage basin that supplies most of the water. Variation in natural storage combined with variations in precipitation, topography, soil, and exposure, combine to produce a variable runoff throughout the region. In many closely adjacent areas of the Puget Basin changes in runoff are abrupt.

The U. S. Army Corps of Engineers has analyzed parts of the drainage basin for precipitation and loss-runoff characteristics. However, the results are significant only for comparative purposes within the given watershed areas. Values for precipitation seem high in the light of similar figures available from other sources. The data are shown in Table 3-4. Values for total runoff for the entire Puget Basin in acre-feet are not available due to incomplete records on many individual streams.

ANALYSIS OF RIVER DISCHARGES

During the years in which river gaging stations have been operated in the Puget Basin 81 per cent of the total area has been gaged. However, many stations have been operated for one water year or less and then discontinued.

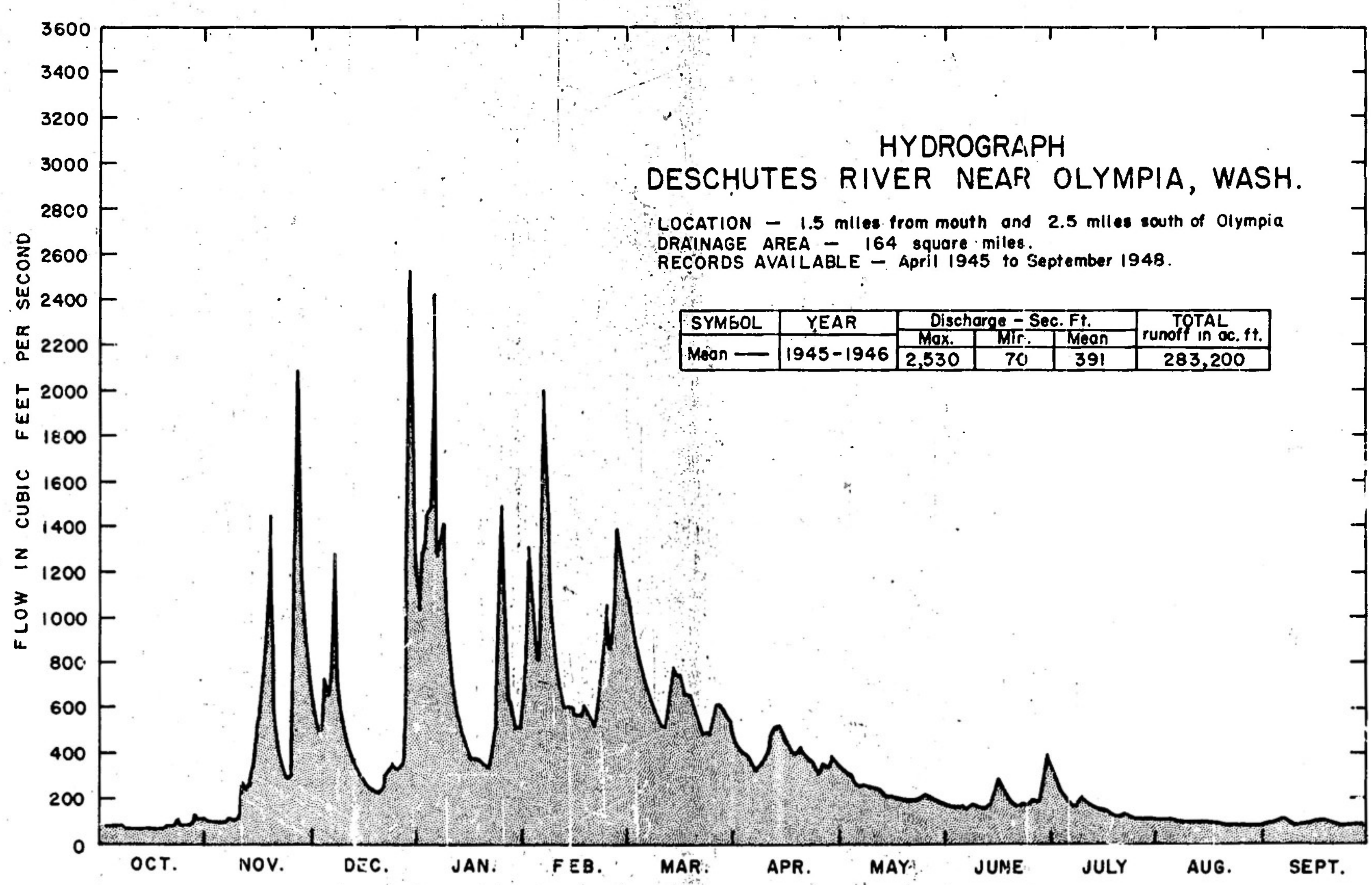

HYDROGRAPH
DESCHUTES RIVER NEAR OLYMPIA, WASH.
LOCATION — 1.5 miles from mouth and 2.5 miles south of Olympia
DRAINAGE AREA — 164 square miles.
RECORDS AVAILABLE — April 1945 to September 1948.
SYMBOL | YEAR | Discharge - Sec. Ft. Max. Min. Mean | TOTAL runoff in ac. ft.
Mean —— | 1945-1946 | 2,530 | 70 | 391 | 283,200
FLOW IN CUBIC FEET PER SECOND
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.

Fig. 3-5

The gaged runoff, maximum, mean, and minimum flow entering the Sound, are shown in detailed analysis in Table 3-5. The column headed "Maximum" gives the maximum daily discharge, not the momentary discharge when the water surface was at its crest stage. Likewise, in the column headed "Minimum" the quantity given is the minimum daily discharge. The column headed "Mean" gives the average flow in cubic feet per second during the month. The short term records shown for many stations provide little conclusive data for variation in flow, for comparative monthly periods may exceed 300 per cent. Ground water (to be discussed later) may account for a much higher water yield from the basin than one may ordinarily expect when examining only surface runoff records.

Fraser River Influence

Located approximately 90 miles north of Point Partridge, a northern boundary point for Puget Sound, the Fraser River discharges into the Strait of Georgia. The Fraser River water is known to dilute the salt water in the approaches to Puget Sound (see section on Oceanography). The Fraser River at Hope, B.C., approximately 95 miles from the river's mouth has a drainage area of 85,600 square miles, eight times the size of the entire Puget Sound Basin. During the period of record 1912 to 1946 the maximum discharge for the Fraser River was 392,000 second-feet (June 1921), the minimum was 12,000 second-feet (January 1916), with a mean flow for the water year 1945-46 of 89,000 second-feet (Canada Department of Resources and Development 1950). The extreme flow of the Fraser River is approximately equal to the extreme flow for the entire Puget Basin but the mean flow of the Fraser is approximately twice that for the Puget Basin.

CONTROL AND DIVERSION OF RIVERS

Diversions and controls of several types complicate the surface runoff records for Puget Sound. Man-made changes in river courses, dams, and reservoirs will alter the natural flow of water by equalizing periods of runoff and diverting or by-passing water from the gaging stations, and in some cases, actually diverting water away from Puget Sound. The history of a few of the major diversion projects will be considered to provide an historical background for any sedimentation or circulation problems that may be considered for Puget Sound.

Diversion of the White River into the Puyallup River

Prior to 1906, the Puyallup River received only a fractional part of the water flowing in the White River (some observers estimated one-third), the remainder discharged into the Green River and then through the Duwamish into Elliott Bay at Seattle.

TABLE 3-4. Normal Seasonal Precipitation, Loss-Runoff Data for Lower Gaging Stations in the Puget Sound Basin.

STREAM GAGING STATION	DRAINAGE AREA	RUNOFF	PRECIPITATION	LOSS
Skagit River at Sedro Woolley	2970	73.8	93.5	19.7
North Fork Stillaguamish River near Arlington	269	100.6	121.5	20.9
South Fork Stillaguamish River near Arlington	254	108.0	121.7	13.7
Snoqualmie River near Tolt	605	84.5	99.9	15.4
Skykomish River near Gold Bar	535	99.2	117.7	18.5
Cedar River near Landsburg	138	67.0	90.1	23.1
Green River near Auburn	386	48.9	65.9	17.0
Puyallup River at Puyallup	948	47.3	61.8	14.5
Nisqually River near La Grande	287	64.7	83.2	18.5
South Fork Skokomish near Union	81	110.0	129.3	19.3
Hamma Hamma River near Hoodsport	84	75.1	96.2	21.1
Duckabush River near Brinnon	66	110.6	127.5	16.9
Dosewallips River near Brinnon	94	92.5	116.6	24.1

Data from Normal Seasonal Precipitation Loss-Runoff Map (U. S. Army Corps of Engineers 1946).

TABLE 3-5. Discharge Data for the Puget Sound Basin [In second-feet].

DRAINAGE BASIN OR AREA AND LOWEST GAGING STATIONS	Period of Record	Years Evaluated	Max. Flow	Date of Record	Min. Flow	Date of Record	Mean Flow	% of Total Mean Flow	Runoff [Inches]	Source
SKAGIT										
Skagit River near Mount Vernon	1940-	1940-48	94,300	10/45	2,740	10/42	14,345	34.95	63.0	WSP
STILLAGUAMISH										
North Fork near Arlington	1928-	1928-48	27,700	2/32	88	9/38	1,446	3.52	84.8	WSP
South Fork near Arlington	1928-36	1928-36	35,000	2/32	108	9/30	1,810	4.41	96.3	WSP
Church Creek near Stanwood	1950-	1950.	7	9/50	0.1	8-9/50	0.5	-	0.09	UPGS
Portage Creek near Arlington	1950-	1950.	41	9/50	9.2	8/50	13	0.03	1.6	UPGS
Armstrong Creek near Arlington	1950-	1950-51	57	9/50	1.2	9/50	11	0.03	2.2	UPGS
Pilchuck Creek near Bryant	'29-31,'50-	1929-31	3,040	3/30	0.5	8/31	214	0.52	46.1	UPGS
SNOHOMISH										
Snohomish River at Snohomish	1941-	1941-48	64,900	10/47	10,000	7/48	12,473	30.39	-	WSP
Quilceda Creek near Marysville	1946-	1946-48	135	2/48	3.8	8/46	24	0.06	-	WSP
LAKE WASHINGTON										
Sammamish River at Bothell	1939-	1939-48	1,290	2/47	63	8/44	331	0.81	21.4	WSP
Swamp Creek near Bothell	1945.	1945.	17	9/45	2.4	8/45	4	0.01	0.7	WSP
McAleer Creek near Bothell	1945-49	1945-48	102	2/47	1.6	8/45	2	-	13.9	WSP
Thornton Creek near Seattle	1945-46	1945.	48	9/45	2.4	7/45	11	0.03	-	WSP
Juanita Creek near Kirkland	1945.	1945.	48	9/45	1.1	9/45	7	0.02	1.5	WSP
Mercer Creek near Bellevue	1945.	1945.	26	9/45	2.8	7/45	13	0.03	1.1	WSP
Cedar River at Renton	1945-	1946-47	5,650	11/06	97	9/45	877	2.14	54.1	WSP
May Creek near Renton	1945-	1946-47	175	12/46	1.9	7/43	20	0.05	22.0	WSP

TABLE 3-5. Discharge Data for the Puget Sound Basin [In second-feet]. (Continued)

DRAINAGE BASIN OR AREA AND LOWEST GAGING STATIONS	Period of Record	Years Evaluated	Max. Flow	Date of Record	Min. Flow	Date of Record	Mean Flow	% of Total Mean Flow	Runoff [Inches]	Source
DUWAMISH										
Green River near Auburn	1936-	1936-48	22,000	12/46	113	9/40	1,180	2.87	45.4	WSP
PUYALLUP										
Puyallup River at Puyallup	1914-	1914-48	57,000	12/33	350	12/29	3,119	7.60	44.6	WSP
Clark Creek at Puyallup	1946-48	1946-48	27	3/48	10	2/46	19	0.05	-	WSP
Wapato Creek near Tacoma	1949.	1949.	13	10/49	1.5	8/49	4	0.01	0.7	UPGS
Hylebos Creek near Tacoma	1949-50	1949-50	108	3/50	6.4	8/50	12	0.03	11.3	UPGS
NISQUALLY										
Nisqually River at McKenna	1947-	1947-48	11,500	1/48	42	9/48	1,668	4.06	44.5	WSP
Chamber Creek below Leach Creek, near Steilacoom	'39-40, '43-	'39-40, '43-48	281	1/48	3.4	8/40	96	0.23	-	WSP
DESCHUTES										
Deschutes River near Olympia	1945-	1945-48	3,560	1/47	66	10/46	313	0.76	35.4	WSP
Woodward Creek near Olympia	1949.	1949.	13	10/49	2.4	10/49	3	-	1.0	UPGS
Woodland Creek near Olympia	1949-	1949-51	204	2/51	10	9/49	37	0.09	1.5	UPGS
SHELTON										
Mill Creek at Shelton	1942-43	1942-43	474	2/43	11	9/43	62	0.15	3.5	WSP
Goldsborough Creek at Shelton	1942-43	1942-43	950	2/43	13	9/43	98	0.24	21.8	WSP
Johns Creek near Shelton	'42-43, '48-50	1942-43	105	2/43	5.5	9/43	28	0.07	1.6	WSP
Deer Creek near Shelton	'42-43, '48-50	1942-43	205	2/43	6.3	9/43	31	0.08	2.3	WSP
Cranberry Creek near Shelton	'42-43, '48-	1942-43	232	2/43	16	9/43	41	0.10	3.4	WSP

TABLE 3-5. Discharge Data for the Puget Sound Basin [In second-feet]. (Continued)

DRAINAGE BASIN OR AREA AND LOWEST GAGING STATIONS	Period of Record	Years Evaluated	Max. Flow	Date of Record	Min. Flow	Date of Record	Mean Flow	% of Total Mean Flow	Runoff [Inches]	Source
GREAT PENINSULA INTO PUGET SOUND										
Burley Creek at Burley	1947-50	1947-48	255	10/47	11	7/47	34	0.08	4.2	WSP
Huge Creek near Wauna	1947-	1947-48	59	3/48	3.5	9/47	13	0.03	23.0	WSP
Blackjack Creek at Port Orchard	1947-50	1947-48	228	3/48	6.7	7-9/47	22	0.05	-	WSP
Chico Creek near Bremerton	1947-50	1947-48	600	1/48	0.0	8-9/47	37	0.09	-	WSP
Clear Creek near Silverdale	1947.	1947.	9	9/47	1.5	7/47	3	0.01	-	WSP
Dogfish Creek near Poulsbo	1947-	1947-48	93	1/48	1.8	8/47	7	0.02	5.8	WSP
GREAT PENINSULA INTO HOOD CANAL										
Stavis Creek near Seabeck	1947.	1947.	39	10/47	6.3	7/47	6	0.01	-	WSP
Anderson Creek near Holly	1947.	1947.	12	10/47	4.8	7/47	5	0.01	-	WSP
Dewatto Creek near Dewatto	1947-	1947-48	660	10/47	11	9/47	52	0.13	49.9	WSP
Tahuya River near Tahuya	1947.	1947.	30	10/47	6.9	9/47	10	0.03	-	WSP
Gold Creek near Bremerton	1945-	'45,'47-48	58	10/47	0.3	10/45	5	0.01	48.5	WSP
Panther Creek near Bremerton	1945-	'45,'47-48	43	10/47	0.0	9/48	6	0.01	34.9	WSP
Mission Creek near Belfair	1945-	'45,'47-48	140	2/47	0.1	7,9-10/47	10	0.03	28.7	WSP
Union River near Belfair	1947-	1948.	1,090	10/47	13	9/47	30	0.08	-	WSP
SKOKOMISH										
Skokomish River near Potlatch	1943-	1943-48	16,700	2/45	125	9/44	967	2.36	57.0	WSP
HAMMA HAMMA										
Hamma Hamma River near Hoodsport	1926-30	1926-29	5,080	12/26	23	9/29	462	1.13	70.6	WSP

TABLE 3-5. Discharge Data for the Puget Sound Basin [In second-feet]. (Continued)

DRAINAGE BASIN OR AREA AND LOWEST GAGING STATIONS	Period of Record	Years Evaluated	Max. Flow	Date of Record	Min. Flow	Date of Record	Mean Flow	% of Total Mean Flow	Runoff [Inches]	Source
DUCKABUSH										
Duckabush River near Brinnon	'10-11, '38-	1938-48	6,080	12/39	45	10/42	375	0.91	73.1	WSP
DOSEWALLIPS										
Dosewallips River at Brinnon	'10-11, '24-25 '28-30	'25, '27-30	4,920	11/10	19	8/25	421	1.03	41.4	WSP
QUILCENE										
Little Quilcene River near Quilcene	1926-27	1926-27	256	1/27	5.7	10/26	56	0.14	19.0	WSP
Big Quilcene River near Quilcene	1926-27	1926-27	1,620	12/26	24	9/26	214	0.52	49.2	WSP
PUGET SOUND (Total)	-	-	367,180	-	14,088	-	41,047	100.00	-	-

WSP - Water Supply Papers, Geological Survey

UPGS - Unpublished Gaging Sheets, Geological Survey, Tacoma, Washington

During a flood in November 1906, the Duwamish branch of the White River became jammed with drift, closing that branch completely, and turning all the water of the White southward through the Stuck River Tributary to the Puyallup River which then emptied into Commencement Bay at Tacoma. At the peak of this flood, the estimated discharge of the Puyallup River at Puyallup was 36,000 second-feet, which was beyond any previous record, and proved to be especially destructive.

In 1915, a drift barrier of original design was constructed on the White River near Auburn to catch and hold the forest debris and a concrete embankment or dam was constructed near Auburn to close the north distributary of the White River permanently.

Diversion of the Cedar River into Lake Washington

In 1917 when the Lake Washington Ship Canal was built to join Lake Washington with Puget Sound, the level of Lake Washington was lowered approximately ten feet to the level of Lake Union, lying between Lake Washington and Puget Sound. Due to lowering Lake Washington, the Black River which formerly carried the water from Lake Washington into the Duwamish River was left dry. At this time the Cedar River which joined the Black River at a point only a few miles from Lake Washington now formed a new channel and flowed directly into Lake Washington (Dart 1952).

Other River and Stream Diversions

Table 3-6 describes the location of projects located along the rivers that tend to alter the flow of water from a normal expected pattern to one controlled, in part, by man. Many small diversions are not enumerated. Any forecasting procedures will be required to evaluate the magnitude of these diversions.

MAJOR RIVER DRAINAGE BASINS

The number of rivers entering Puget Sound is an important factor when their distribution along the shore line is taken into consideration. It may be observed that several of the rivers carry almost all the water when the total flow is examined. The Skagit and Snohomish Rivers each carry one-third of the total runoff and both enter northern Puget Sound through the Possession Sound system. The remaining third is fairly well distributed. Four representative streams are described below. The factors are not uniformly described due to lack of available information.

TABLE 3-6. Location of River Control Systems.

DRAINAGE BASIN, RIVER, AND PROJECT	OPERATION*	BASIN AREA AFFECTED**	% OF TOTAL BASIN AREA	PURPOSE AND AUTHORITY
SKAGIT BASIN				
Skagit River				
Ross Dam and Reservoir	Regulation	978	30.6	Power Development, Seattle City Light
Diablo Dam and Reservoir	Regulation	1,100	34.5	Power Development, Seattle City Light
Skagit River near Mt. Vernon	Diversion	3,060	95.9	Municipal Water Supply, City of Anacortes
Baker River				
Lake Shannon Dam and Reservoir	Regulation	270	8.5	Power Development, Puget Sound Power and Light Company
SNOHOMISH BASIN				
Pilchuck River				
Pilchuck River near Granite Falls	Diversion	53	3.1	Municipal Water Supply, City of Snohomish
Sultan River				
Lake Chaplain Reservoir***	Diversion	-	-	Municipal Water Supply, City of Everett
LAKE WASHINGTON BASIN				
Cedar River				
Cedar Lake Reservoir	Regulation	78	14.3	Power Development, Seattle City Light
Cedar River at Renton	Diversion	197	36.1	Municipal Water Supply, City of Seattle

*Diversion occurs above lowest gaging station
**In square miles
***Off stream

TABLE 3-6. Location of River Control Systems. (Continued)

DRAINAGE BASIN, RIVER, AND PROJECT	OPERATION*	BASIN AREA AFFECTED**	% OF TOTAL BASIN AREA	PURPOSE AND AUTHORITY
DUWAMISH BASIN				
Green River				
Green River near Auburn	Diversion	386	79.1	Municipal Water Supply, City of Tacoma
PUYALLUP BASIN				
Puyallup River				
Puyallup River near Electron	Regulation	93	9.2	Power Development, Puget Sound Power and Light Company
White River				
Mud Mountain Dam and Reservoir	Regulation	400	39.6	Flood Control, U. S. Corps of Engineers
Lake Tapps Reservoir***	Diversion	-	-	Power Development, Puget Sound Power and Light Company
NISQUALLY BASIN				
Nisqually River				
Alder Dam and Reservoir	Regulation	287	35.0	Power Development, Tacoma City Light
LaGrande Dam and Reservoir	Regulation	296	36.1	Power Development, Tacoma City Light
Nisqually River near KcKenna	Regulation	445	54.2	Power Development, City of Centralia Irrigation Project, Yelm Irrigation Dist.
Paradise River				
Paradise River near National	Regulation	-	-	Power Development, Rainier National Park
Mashel River				
Eatonville Millpond	Regulation	52	6.3	Log Pond for Sawmill at Eatonville
Mashel River near LaGrande	Diversion	79	9.6	Municipal Water Supply, City of Eatonville

*Diversion occurs above lowest gaging station.
**In square miles
***Off stream

TABLE 3-6. Location of River Control Systems. (Continued)

DRAINAGE BASIN, RIVER, AND PROJECT	OPERATION*	BASIN AREA AFFECTED**	% OF TOTAL BASIN AREA	PURPOSE AND AUTHORITY
SKOKOMISH BASIN				
North Fork Skokomish River				
Cushman Dam and Reservoir				
No. 1	Regulation	91	31.8	Power Development, Tacoma City Light
No. 2	Regulation	96	33.6	Power Development, Tacoma City Light
GREAT PENINSULA INTO HOOD CANAL				
Union River				
Union River near Belfair, Wash.	Diversion	19	8.3	Municipal Water Supply, City of Bremerton
OTHERS				
Chamber Creek near Steilacoom	Regulation	-	-	Flood Control, U. S. Corps of Engineers

*Diversion occurs above lowest gaging station
**In square miles

Skagit River

The Skagit River, the largest river by volume of flow in the Puget Basin, carries approximately 35 per cent of the total mean flow of water into Puget Sound. A general description of the Skagit River has been summarized from U. S. Army Corps of Engineers 1934c and other sources.

DRAINAGE AREA. Skagit River has its source in the Cascade Mountains in Canada, 28 miles by river, north of the International boundary. It flows in a general southwestward direction about 163 miles to enter Skagit Bay, an arm of Puget Sound. Below Mount Vernon, about 10 miles above the mouth, the river flows through a delta in two main channels, the North Fork and the South Fork, and a number of minor channels. The drainage area of the basin is about 3,191 square miles, 390 square miles of which are in Canada. Two-thirds of the area is included in national forests. Elevations range up to 10,000 feet and more in the headwater regions.

WATERSHED. The streams in the watershed flow through canyons and narrow valleys with steep gradients. The gradient of the main stream average about 13 feet per mile for the first 30 miles of its course south of the Canadian border. It then drops abruptly 700 feet in the next 12 miles, below which it averages about 6 feet per mile for the next 80 miles, to tidewater. The river is tidal to the Great Northern Railway bridge 15.4 miles above the mouth, the mean diurnal range at the mouth being 11.1 feet and the extreme range 19 feet.

Two regulating dams, Ross Dam and Reservoir and Diablo Dam and Reservoir affect 978 and 1,100 square miles of watershed respectively. A diversion system for supplying water to the city of Anacortes is located at Mount Vernon. The Baker River, tributary to the lower Skagit, has a regulation dam, Lake Shannon Dam and Reservoir, affecting 270 square miles of watershed.

TEMPERATURE AND PRECIPITATION. Air temperatures along the course of the Skagit range from -11° to over 100° F. with an annual mean of about 50° F. throughout the valley. Precipitation varies from over 100 inches per year in the mountainous portions to less than 30 inches in the lowlands, 80 per cent of which usually falls during the wet season from October to April. Much of the precipitation falls as snow, the snowfall varying from less than 12 inches along the coast to about 500 inches at the higher elevations.

TYPE OF RUNOFF. Rugged topography, large and concentrated precipitation, about 64 square miles of glaciers, and absence of natural reservoirs combine to produce an erratic and flash-runoff. Floods may occur at any time of the year due to warm weather and rains melting accumulated snow. In the lower valley where floods cause the only extensive inundation, the maximum rates of flow occur during the winter months but the maximum monthly runoff usually occurs in June. Low-water periods occur during cold weather or in the autumn. Discharge fluctuates between 2,740 and 94,300 cubic feet per second and averages about 14,345. See Table 3-7 for discharge figures.

FLOOD CONDITIONS. The Skagit River has been subject to flooding. Floods are caused by warm, moisture-laden winds known as "Chinooks," which melt the glaciers and accumulated snow with great rapidity (see section on Climatology: Chinook Wind). They may occur at any time of the year but the largest are generally in November and December. Between the years 1869 and 1934 there have been five major floods with peak discharges at The Dalles (mile 54) varying from 180,000 to 270,000 cubic feet per second. The flood which occurred about 1915 is estimated to have had a peak discharge at The Dalles of 480,000 cubic feet per second. The crest of the flood is materially reduced prior to reaching Puget Sound as the river breaks through the levies and overflows the banks before reaching Mount Vernon. Control is offered by the several regulation and diversion dams along the course of the river.

Snohomish River

The Snohomish River carries approximately 30 per cent of the total mean flow of water into Puget Sound. The following description has been summarized from U. S. Army Corps of Engineers 1934d and other sources.

DRAINAGE AREA. The Snohomish River drains an area of about 1,734 square miles lying between the Cascade Mountains and Puget Sound. The Snohomish is formed by the junction of its two principal tributaries, the Skykomish and the Snoqualmie. From this junction it flows northwest 22 miles to enter Port Gardner, an arm of Puget Sound, at Everett. The upper 6 miles of the river lie in a narrow valley. In the lower reaches the river divides into several delta channels flowing through low-lying lands subject to inundation. Extensive tide flats extend out from the mouths of the river.

WATERSHED. Gradient on the main stream and on the lower reaches of the tributaries average about 3 feet per mile, but as the headwater regions are approached the gradient rapidly increases and numerous falls

TABLE 3-7. Discharge of Skagit River near Mount Vernon. [In second-feet]

YEAR ENDING SEP.30	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
1941		9,880	14,290	10,310	8,654	8,487	11,080	15,880	14,970	9,820	6,441	11,450	-
1942	17,330	13,860	20,490	7,636	7,626	6,856	11,510	16,870	25,400	17,230	8,373	5,023	13,220
1943	4,323	13,380	15,710	11,730	11,970	11,600	23,360	21,660	31,420	29,840	11,430	7,183	16,140
1944	8,100	6,592	10,670	9,965	8,044	7,878	10,610	17,400	19,620	10,430	6,835	9,945	10,510
1945	8,736	10,810	10,930	15,950	14,860	9,714	10,130	25,960	25,370	16,170	8,083	8,469	13,760
1946	14,340	17,990	12,540	13,670	10,680	12,820	16,580	36,530	32,810	23,750	10,590	6,745	17,460
1947	8,957	9,351	18,200	12,800	16,430	14,460	17,720	24,720	25,740	15,780	8,319	7,390	14,980
1948	19,110	15,670	19,050	15,180	10,380	8,448	11,800	24,680	39,280	20,380	13,760	11,590	17,460
1949	12,820	13,290	12,840	9,015	12,020	15,200	17,900	33,920	24,470	20,010	13,320	10,910	16,340
1950	12,970	23,740	21,830	15,560	19,740	22,810	17,720	22,020	37,920	35,710	17,060	10,200	21,440
1951	17,120	21,000	30,560	19,650	31,140	11,760	19,580	26,400	21,700	17,460	9,269	8,329	19,420

Table from U. S. Department of the Interior Geological Survey n.d.f.

occur. The eastern portion of the watershed is rugged and mountainous in character, the peaks reaching an altitude of 7,000 feet, but passing westward elevations gradually decrease. Over 50 per cent of the area is in national forest reserve. Two principal diversion systems are located on streams tributary to the Snohomish, these on the Pilchuck and Sultan Rivers.

The stream is from 400 to 1,000 feet in width and is tidal for a distance of 18 miles, the mean tidal range at the mouth being 11.3 feet and the extreme range 18 feet.

TEMPERATURE AND PRECIPITATION. Temperatures range from -15° to over 100° F. with an annual mean of about 50° F. throughout the valley. Precipitation varies from over 100 inches per year in the mountainous portion to about 33 inches in the lowlands, 80 per cent of which usually falls during the wet season of October to April. Much of the precipitation falls as snow, the snowfall varying from about 13 inches on the coast to over 300 inches at the higher elevations.

TYPE OF RUNOFF. Rugged topography, abundant and concentrated precipitation, and absence of large natural reservoirs combine to produce an erratic and flashy runoff. Floods may occur at any time of the year due to rains and warm weather melting the accumulated snowfall, but the maximum monthly flow usually occurs either in the period from November to February or in the period from May to June. The discharge fluctuates between 10,000 and 64,900 cubic feet per second and averages 12,473. Long-time continuous records of streamflow do not exist. The low water flow usually occurs between August and October when precipitation is small.

FLOOD CONDITIONS. The valley of the Snohomish and of the lower portions of its tributaries are subject to damaging floods. From the limited data available it is estimated that damaging floods may occur on the average of once in 5 years, and that floods on the lower river may vary from 45,000 to 200,000 second-feet. Floods may occur any time of the year due to melting of accumulated snow. Damaging floods usually occur in November or December.

Puyallup River

The Puyallup River carries approximately 7.6 per cent of the total mean flow of water into Puget Sound. The following description has been summarized from U. S. Army Corps of Engineers 1932a and other sources.

DRAINAGE AREA. The Puyallup River has its source on the western slopes of Mount Rainier and flows northwest to Commencement Bay by the city of Tacoma. It has a length of about 50 miles and a total fall of more than 3,000 feet. Elevations within the drainage basin of the Puyallup range from sea level at Tacoma to 14,408 feet at the summit of Mount Rainier. Portions of the Cascades drained by Greenwater River reach 6,600 feet. The feet of the glaciers on Mount Rainier lie at elevations between 4,300 and 4,700 feet. The extremely rugged topography in the vicinity of Mount Rainier covers only a small portion of the drainage basin. Between the mouth of Mowich River and Electron, which is situated at the lower end of the Puyallup Canyon, the ridges are high and steep, but well covered with alluvial material and glacial drift. The lower portion of the entire basin comprises rolling lowlands and flat areas common to the entire region.

WATERSHED. The Puyallup watershed comprises 1,009 square miles, 288 being in Snoqualmie National Forest and 192 in Mount Rainier National Park. The Puyallup and its principal tributaries, the Mowich, Carbon, and White Rivers, all head in the glaciers of Mount Rainier, the Puyallup and the Mowich flowing from the west and northwesterly glaciers, the Carbon and White from the northern and eastern ice fields. The Greenwater, a branch of the White, drains the easternmost portion of the basin, heading in the Cascade range. All of the streams, except the Greenwater, carry enormous burdens of glacial silt. About three-fourths of the glacial area of Mount Rainier is tributary to the Puyallup River. Discharge fluctuates between 350 and 57,000 cubic feet per second and averages about 3,119. See Table 3-8 for discharge figures. The river is generally shallow and at the mouth is subject to a tidal range of 11.8 feet. A regulation dam near Electron affects approximately 93 square miles of the watershed area.

PRECIPITATION. The mean annual rainfall in the mountainous portion of the Puyallup Basin exceeds 100 inches, it decreases gradually to about 39 inches in the lowlands. About 80 per cent falls during the wet season which begins October or November and lasts 6 or 7 months. November, December, and January are the months of greatest precipitation. June, July, and August are the lowest. On the summits and upper slopes the greater part of the precipitation is from the snowfall in winter, the summer rainfall being light. Snowfall on the altitudes between 6,000 and 10,000 feet generally exceeds 500 inches annually, decreasing to about 12 inches in the lower valley.

TABLE 3-8. Discharge of Puyallup River at Puyallup. [In second-feet]

YEAR ENDING SEP.30	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
1934	4,316	4,634	15,790	8,024	4,163	5,060	4,236	4,751	2,663	2,066	1,797	1,330	4,927
1935	3,702	6,011	4,427	6,196	3,574	3,098	2,894	3,232	4,269	3,184	1,862	1,390	3,654
1936	969	1,322	1,557	4,778	2,232	3,706	4,410	6,681	6,060	3,225	2,217	1,618	3,235
1937	1,197	820	3,391	1,335	2,404	3,139	4,240	4,124	6,415	3,308	1,841	1,638	2,819
1938	1,543	6,430	5,219	4,225	2,218	2,654	4,931	4,500	4,089	2,936	1,877	1,620	3,523
1939	1,593	2,462	3,467	3,749	3,111	3,506	3,378	3,783	4,001	3,062	2,041	1,450	2,967
1940	1,264	1,674	3,752	3,062	4,569	3,963	3,055	3,650	2,477	2,049	1,714	1,547	2,727
1941	1,566	2,180	2,591	2,300	1,521	1,598	2,146	2,661	2,702	2,205	1,713	1,359	2,090
1942	2,314	2,645	4,868	2,303	2,458	1,940	2,504	3,545	5,171	3,667	2,181	1,367	2,917
1943	1,118	4,222	4,633	2,908	4,136	2,719	4,601	3,349	4,490	3,373	1,769	1,532	3,225
1944	1,508	1,484	3,056	2,033	2,298	2,074	2,208	3,036	2,970	2,078	1,614	1,833	2,183
1945	1,310	1,548	2,118	4,760	3,954	2,724	3,432	4,959	3,612	2,358	1,765	2,156	2,885
1946	1,808	4,324	4,616	5,042	4,053	4,282	4,035	5,521	5,327	3,882	2,085	1,397	3,864
1947	2,191	3,812	7,520	4,394	4,080	3,175	3,924	3,937	3,815	2,490	1,512	1,620	3,537
1948	3,944	5,632	4,463	4,115	3,773	3,015	3,297	5,264	6,941	3,459	2,433	1,835	4,011
1949	2,170	3,522	4,311	1,800	3,761	3,778	4,301	6,440	4,600	3,233	2,119	1,531	3,461
1950	2,207	4,050	4,637	4,359	5,045	5,904	4,309	4,702	6,914	5,182	2,636	1,714	4,299
1951	3,137	5,521	6,504	4,832	7,123	3,365	3,590	4,294	3,704	2,583	1,735	1,403	3,961

Table from U. S. Department of the Interior Geological Survey n.d.f.

Note: For results prior to October 1933, see Washington State Water-Supply Bulletin No. 5. Corrected for storage regulation in Lake Tapps Reservoir beginning October 1934, and Mud Mountain Reservoir beginning October 1944. Beginning October 1947 corrected only for storage regulation in Lake Tapps.

Skokomish River

The Skokomish River carries approximately 2.4 per cent of the total mean flow of water into Puget Sound. The following description of the Skokomish River has been summarized from U. S. Army Corps of Engineers 1943 and other sources.

DRAINAGE AREA. This drainage area is about 23 miles long and 15 miles wide at the widest part, with its major axis extending in a northwesterly-southeasterly direction. Comprising about 286 square miles, the basin is drained by three streams, which combine to form the Skokomish River about 8.9 miles from its mouth. These three streams are the North Fork, which drains about 114 square miles in the northern and eastern parts of the basin; the South Fork, which drains about 83 square miles in the central and western parts of the basin; and Vance Creek (sometimes locally called the West Fork) which drains about 34 square miles of the southern part of the basin.

WATERSHED. The watershed, except in the vicinity of the mouth of the river, is entirely in the Olympic Mountains and the adjacent foothills. Elevations range from sea level at the mouth of the river to more than 6,400 feet on the highest peak. The area is characterized by steep slopes which are heavily wooded up to about 4,500 feet. These slopes have been deeply dissected by numerous small mountain streams, some of which have their source in small glaciers on the north slopes of the higher peaks, or in small mountain lakes. These streams discharge into the three principal tributaries which flow through deep narrow valleys to within a mile or two of the flood plain near the river mouth. Here the valleys begin to broaden and they join to form the head of Skokomish Valley near the confluent point of the three tributaries. The valley, which is about 9 miles long, varies in width from one-half mile at its upper end to more than 2 miles at the river mouth on Hood Canal, an arm of Puget Sound. Two regulation dams, Cushman Dams numbers 1 and 2, both located on the north fork, control the flow from the north.

The gradients of the streams in the watershed are steep, varying from about 1,000 feet a mile in the upper reaches to between 100 and 20 feet a mile as they approach the lower valley. The average gradient of the Skokomish River through its valley is about 5.5 feet in a mile. Discharge fluctuates between 125 and 16,700 cubic feet per second and averages 967. See Table 3-9 for discharge figures.

FLOOD CONDITIONS. The bankfull capacity of the Skokomish River channel is about 13,000 second-feet. The capacities of the tributary streams are not known, but as their channels during floods are shifted, filled, or enlarged by erosion, it is probable that their bankfull capacity has varied widely from time to time.

TABLE 3-9. Discharge of Skokomish River near Potlatch. [In second-feet]

YEAR ENDING SEP.30	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
1943										296	197	161	-
1944	470	557	1,324	1,660	1,012	789	833	504	308	189	144	150	662
1945	284	1,761	999	1,715	2,316	1,725	959	1,125	426	217	175	225	985
1946	377	1,981	2,467	2,147	1,776	1,722	1,666	1,221	1,146	734	219	194	1,301
1947	427	1,386	2,674	1,578	3,048	772	643	497	341	297	202	201	993
1948	2,436	1,279	2,074	1,903	1,306	1,033	1,184	1,675	692	310	229	585	1,228
1949	739	1,924	1,807	524	2,112	2,151	1,181	1,147	506	307	225	287	1,068
1950	476	2,802	3,179	1,912	2,568	3,241	1,624	1,049	837	462	313	213	1,550

Table from U. S. Department of the Interior Geological Survey n.d.f.

Note: Does not include diversion through Cushman Power installation No. 2.

GROUND WATER

DISTRIBUTION

The ground water of the Puget Sound Basin is found in the glacial deposits. Runoff from ground water contributes an unknown percentage of the total water yield from the Puget Basin. The southern portion of the basin is well supplied with ground water due to the very thick glacial deposits. See section on Geology: Pleistocene Stratigraphy. From Everett northward the supply of ground water is limited and the water of poor quality.

In Whatcom County the greatest supply of ground water is obtained from Vashon outwash gravels. Wells with diameters of ten or twelve inches will commonly yield from 200 to 400 gallons of water per minute (Newcomb 1949).

The area south of Everett is generally well supplied with ground water, but certain portions of the area are unproductive due to the presence of fine sands and silts in the glacial deposits. The presence of these impermeable materials probably accounts for the absence of productive wells along the shore of Puget Sound from Everett to Seattle (Jannsen 1937). The drainage is diverted to the east and follows a course to Lake Washington. It is thought that wells with a capacity of 500 million gallons of water per day are possible in the eastern portion of this area (Jannsen 1952a).

The east side of the valley which extends from Lake Washington to Tacoma has a large supply of ground water under pressure, but the western side of the valley yields little water.

The region from Tacoma southward has the greatest supply of ground water in the Puget Sound Basin. The city of Tacoma has five wells which together yield 32 million gallons of water per day with negligible draw-down, and they could possibly yield 70 million to 80 million gallons per day without overtaxing the supply (Jannsen 1937). The latter flow would be equivalent to 124 cubic feet per second. The water levels in observation wells have remained at the same elevation during the years that the Tacoma wells have been in operation (Watkins 1951).

On the west side of Puget Sound the ground water supply diminishes from south to north. It has been estimated that wells with a capacity of 15 million gallons of water per day could be developed in the Bremerton area (Jannsen 1952b). North of Bremerton the ground water conditions are poorly known. The few wells that have been drilled in this area were either barren or produced very little water.

Bainbridge Island has adequate ground water for domestic use, but the supply is too limited for industry. This same condition is found on the other islands in the northern portion of Puget Sound.

ARTESIAN WELLS

Figure 3-6 shows the major free-flowing water wells near Puget Sound. The heavy concentration of artesian wells in southeastern Puget Sound is clearly shown. Many bluffs and beaches along the perimeter of the Sound have flowing water and seepage visible at all times of the year. In the areas of greatest concentration of ground water many free-flowing wells are found along the beaches. The visible intertidal zone is usually an area of constant seepage. The magnitude of these subterranean flows is unknown but their presence must be strongly felt in the marine waters of Puget Sound as an augmenting force to the surface runoff. The southern Sound area, which receives the lowest percentage of surface water runoff, probably receives the highest percentage of the total ground water runoff in the Puget Basin.

Chloride Content

The unconsolidated pre-Vashon Pleistocene deposits beneath much of the area appears to contain fresh water of low chloride content. The chloride content is high in water from deep wells that penetrate or approach the Tertiary bedrock, wells that enter a series of marine beds of early Vashon age, or wells that tap aquifers cut off from fresh-water recharge and into which sea water has found its way (Newcomb, et.al. 1949).

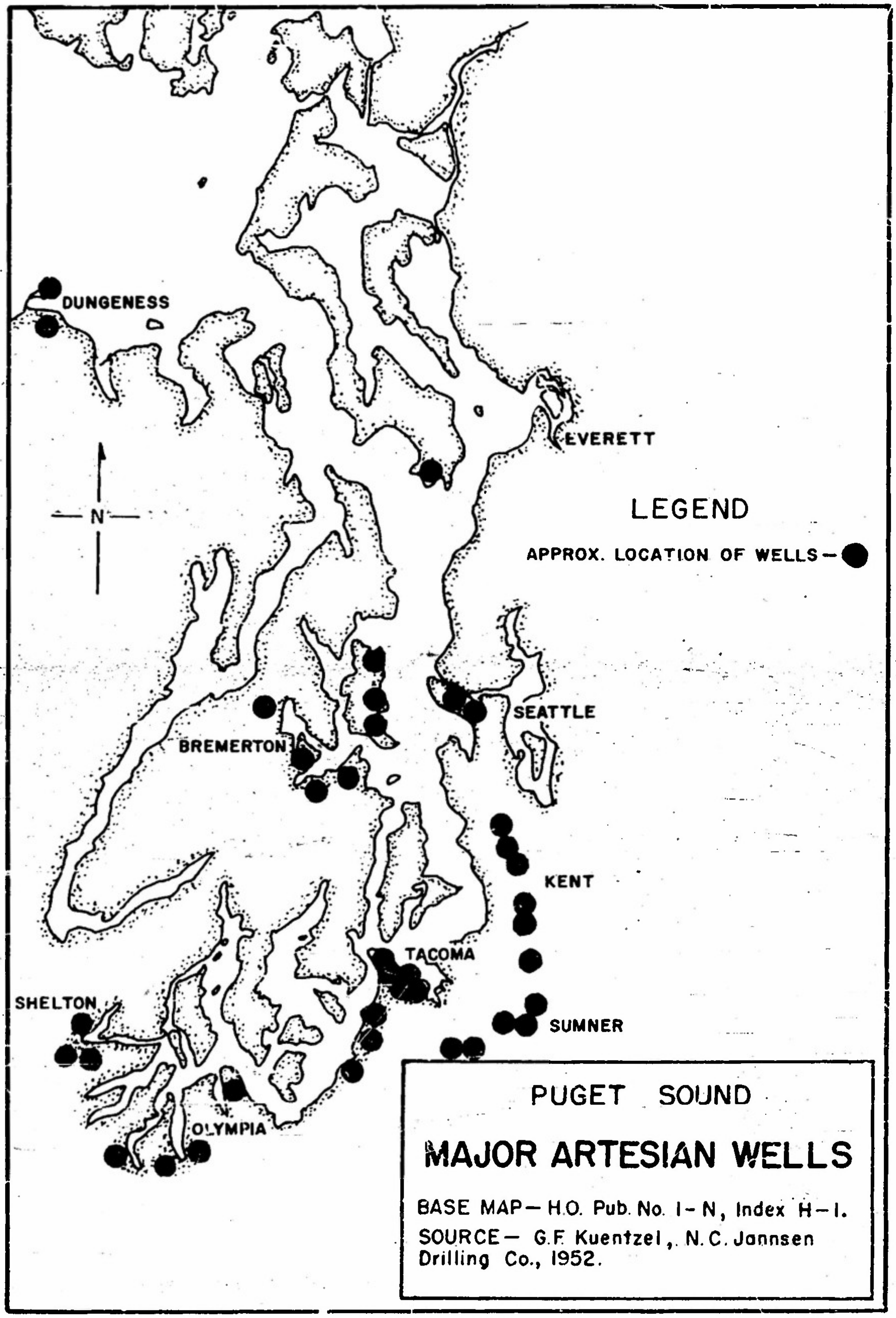

DUNGENESS
EVERETT
N
LEGEND
APPROX. LOCATION OF WELLS —
SEATTLE
BREMERTON
KENT
TACOMA
SHELTON
SUMNER
OLYMPIA
PUGET SOUND
MAJOR ARTESIAN WELLS
BASE MAP— H.O. Pub. No. I-N, Index H-I.
SOURCE— G.F. Kuentzel, N.C. Jannsen Drilling Co., 1952.

Fig. 3-6

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(Bibliography of water supply data, length and area of principal rivers, current gaging station data for records of five or more years, monthly and annual discharge for typical gaging stations, duration of records, and river and reservoir surveys in Washington.

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